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IPASS: An Interactive Policy Analysis Simulation System

Doug Olson, Con Schallau, and Wilbur Maki

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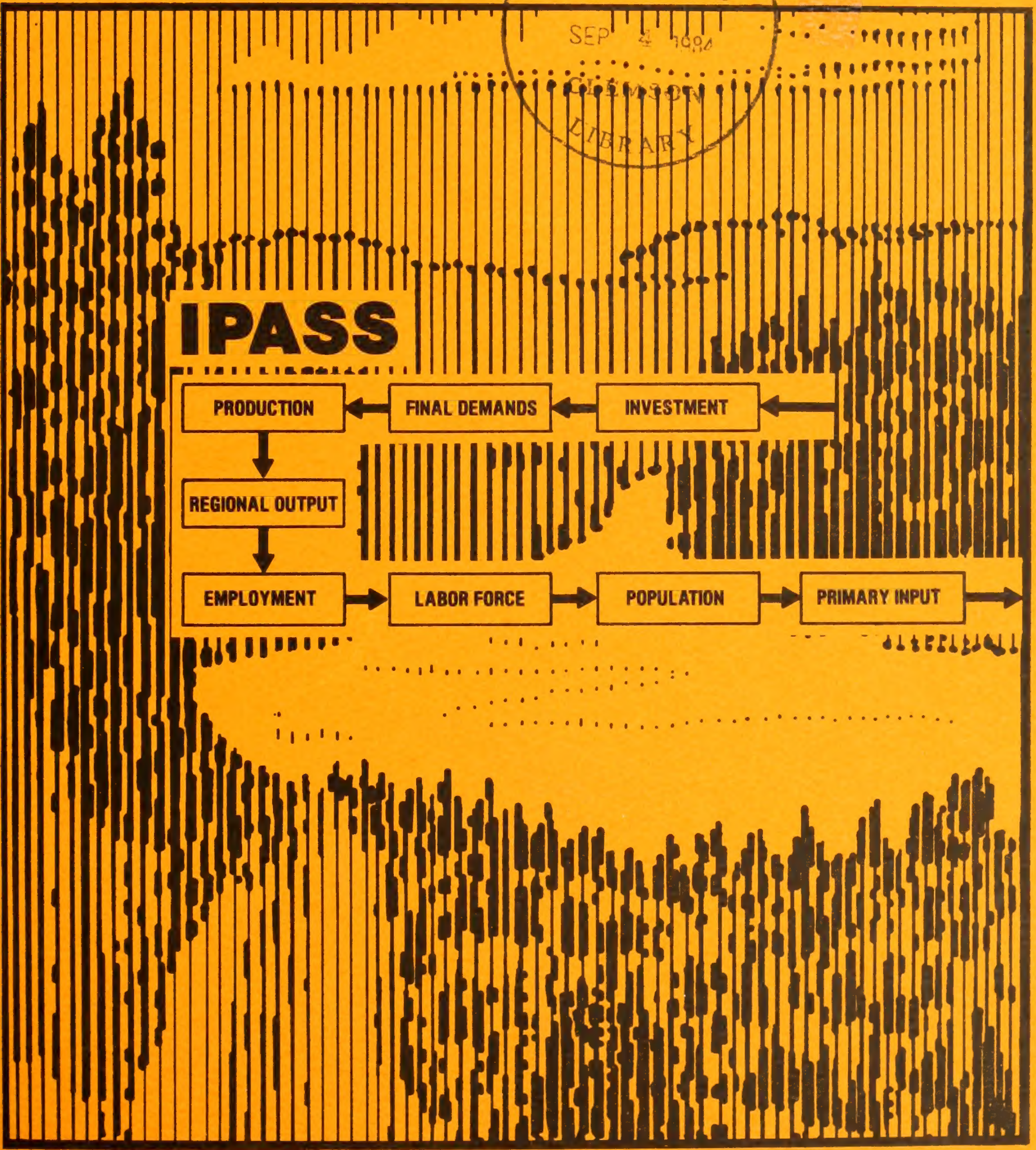

Authors

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Abstract

Olson, Doug; Schallau, Con; Maki, Wilbur. IPASS: an interactive policy analysis simulation system. Gen. Tech. Rep. PNW-170. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 70 p.

This paper describes an interactive policy analysis simulation system (IPASS) that can be used to analyze the long-term economic and demographic effects of alternative forest resource management policies. The IPASS model is a dynamic analytical tool that forecasts growth and development of an economy. It allows the user to introduce changes in selected parameters based on different assumptions about socioeconomic variables. The user can analyze the impact those changes would have on the economy by comparing results of the alternative situation with the original forecast. The program is interactive, and the user needs no previous experience in programing or model building. IPASS has potential use in applied research as well as policy analysis.

Keywords: Economic impact, economic theory (-forest management, resource management, Resources Planning Act (RPA), computer programs/programing.

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Introduction

The management of the Nation's public lands can have a major impact on the economic vitality of the rural West. During the past two decades, for example, nearly half the softwood sawtimber produced in the West came from State and Federal forest lands. Much of the livestock industry west of the 100th meridian is dependent on public grazing permits on lands managed by the U.S. Department of the Interior, Bureau of Land Management, and the U.S. Department of Agriculture, Forest Service. Because National Forests are an important source of goods and services, the Forest Service land management planning process must identify the economic effects of policy changes that might affect dependent communities and their residents.

The Leontief input-output model (I/O) has been used to analyze the direct and indirect effects of alternative National Forest land management policies. An interactive software system, called IMPLAN, was developed by the Forest Service to assist analysts in the construction of I/O models for local areas. This paper describes a dynamic interactive policy analysis simulation system (IPASS) that incorporates the I/O model but enables users to introduce more realism into impact analyses.

IPASS is described in enough detail that readers can decide whether the computational system may be useful to them. The paper also (1) discusses the standard regional input-output (I/O) model, one component of IPASS (fig. 1), (2) compares the static I/O model with the dynamic IPASS simulation model, (3) covers the recursive system of IPASS subroutines, and (4) provides examples to demonstrate the analytical capability of IPASS. An appendix contains a list of parameters and how they can be modified.

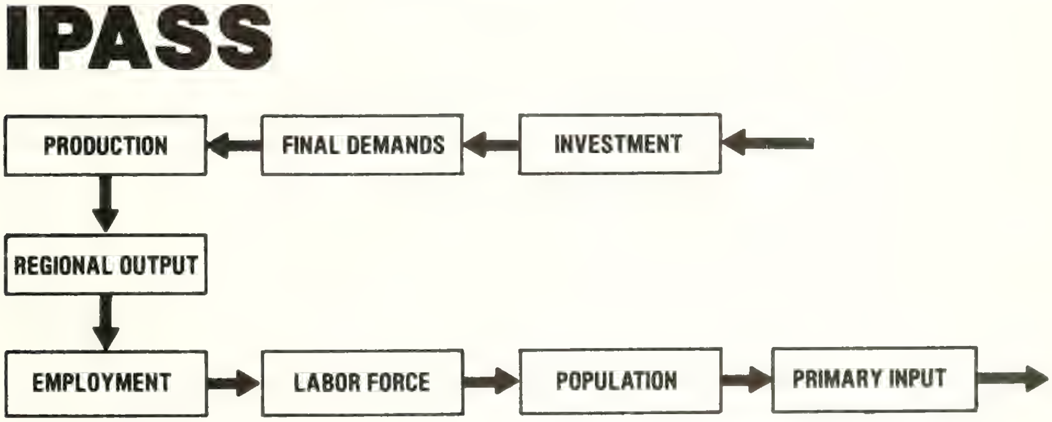

Figure 1.--Fundamental components of the IPASS simulation model. The production module is derived from the ordinary input-output model and is represented here as the Leontief inverse. The remaining modules perform recursively with the production module to form a dynamic regional I/O simulation model.

Input-Output Model

An economy, whether it is local, state, regional, or national, is a complex interaction of many activities: production, consumption, investment, distribution, financing, and others. Manufacturers purchase raw materials, finished goods and services, and labor from suppliers within the local economy or they import these requirements from outside. Similarly, they ship products to users within the economy or export to customers outside the local area. Trade and service sectors provide goods and services to local residents and business establishments. Likewise, various units of local, State, and Federal governments provide a wide range of essential services. Exports provide new dollars for the economy while imports "leak" funds outside the area. An I/O model is an accounting system showing economic transactions between local business, households, and governments, as well as transactions between public and private entities located elsewhere. Although an I/O model provides only a static view of activities, it is a convenient device for characterizing and analyzing complex local, regional, and national economies.

Basic Elements of an Input-Output Model

An input-output model comprises four basic elements: (1) interindustry transactions, which show the purchases of individual local industries from one another, (2) final demands, which are all purchases by sectors other than the local producing industries, (3) primary input purchases and the corresponding income payments to their owners; namely, households, businesses, and government agencies, and (4) individual industry purchases from input-supplying industries outside the area (imports). Direct plus indirect coefficients are derived from these four basic elements. To illustrate the purpose of each element, we will use data from an I/O study of Douglas County, Oregon, by Darr and Fight (1974).

Transaction Table Describes Flow of Products From Local Producers

The table of interindustry transactions is an economist's "vision" of the flow of products from local producers to local users (table 1). This compressed view of the 31-sector model by Darr and Fight is aggregated into 3 sectors: wood products, trade and services, and other local industries. Each sector, which together comprise the "endogenous sector," purchases from and produces goods and services for the others. In 1970, firms comprising the wood products sector purchased $23.0 million worth of goods from each other, $23.6 million from the trade and services sector, and $39.4 million from other local industries. Coincidentally, firms within the wood products sector sold $23.0 to each other, $0.2 million to the trade and services sector, and $6.2 million to other local industries. Together, sales to and purchases from local industries (that is, endogenous transactions) comprise "intermediate transactions."

For small economies like Douglas County, most sales are to nonlocal sectors, or "exogenous markets." Such transactions are termed "final demand," and are represented by a variety of categories such as purchases by households and government, net inventory accumulation, investments, and exports. The wood products sector exported $225.6 million worth of its product to nonlocal users. Similarly, the wood products sector in Douglas County relied on the primary input of their input ($169.0 million worth of goods and services). Primary input was in the form of imported products, payments for wages and salaries to households, government services, entrepreneurial skills, and depreciation.

Table 1--Interindustry transactions for Douglas County, Oregon, 1970

(In millions of dollars)

Disbursing sector	Purchasing sector: Wood products	Purchasing sector: Trade and services	Purchasing sector: Other local industries	Final demand	Total output
Local:					
Wood products	23.0	0.2	6.2	225.6	255.0
Trade and services	23.6	15.7	17.2	166.7	223.2
Other local industries	39.4	11.4	21.4	113.8	186.0
Total	86.0	27.3	44.8	506.1	664.2
Primary input	169.0	195.9	141.2	29.9	536.0
Total input	255.0	223.2	186.0	536.0	1,200.2

Source: Darr and Fight (1974).

The total input column in table 1 indicates total purchases by a local sector from producers inside and outside the local economy. Row totals (total output) are total sales by local sectors to markets inside and outside the local economy. The sum of row totals equals the sum of column totals. This grand total represents Douglas County's gross output of goods and services.

Direct Coefficient Matrix Shows Importance of Local Purchases

The interindustry transaction table is used to determine the amplifying effect of a change in final demand for a sector's products on the gross output of the local economy. This effect is commonly referred to as the I/O multiplier. The size of the multiplier effect for a particular sector is a function of the interdependency between that sector and other local sectors. Final demand is composed of consumer expenditures, private investment, government spending, and exports (shipments to buyers in other regions or abroad). An increase in any or all of these components will increase local income, but a portion of the increase in income will leak out of the local economy in the form of taxes, imports, and savings. The remainder recirculates in the local economy and the process is repeated until there is no more income to spend.

The more an industry purchases from local producers over outside producers, the greater the multiplier effect. To see how this works, consider two hypothetical communities: community "A" and community "B." Presume there are no taxes and nobody saves any income. But presume that for every dollar spent on purchases by community A, $.60 worth is for imported goods and services.
This $.60 represents leakage because it will not recirculate in the local economy. Community B imports $.50 worth of goods and services for every dollar spent on purchases. Is the multiplier effect for community B greater or less than that for A? To answer, we can calculate the multiplier:

Multiplier = 1/leakage fraction;
1.667 = 1/.60 for community A,
2.000 = 1/.50 for community B.

So for community A, the multiplier is 1.6667; for community B, 2.0000. This means that a $1 increase in, say, exports by community B will increase local income by $2, while an increase of $1 in exports by community A would increase income by only $1.67. Because expenditures for imports are not recirculated locally, imports represent leakage from the local economic system. The greater the leakage, the smaller the multiplier effect.

Direct coefficients show the proportion of a sector's total expenditures by source. As illustrated in table 2, the wood products sector purchased a larger proportion of its input from local sectors than did trade and services, and other local industries. Purchases from local sectors account for about one-third of the total expenditures by the wood products sector for goods and services. Trade and services relied on local sectors for only about 12 percent of its input, while other local industries purchased about one-fourth of its needed input from local sectors.

Direct and Indirect Coefficients Matrix Provides Fundamental Answers

The I/O model used in IPASS is a "demand-pull" model. That is, the common question addressed by its user is, "How much is the gross output of goods and services of an economy influenced by a change in final demand?" To answer, the user must have a matrix of direct and indirect coefficients, or "demand" multipliers. These are derived from the relationship:

[Gross output] = [intermediate or local purchases] + [final purchases].

The relationship can be represented mathematically:

$$[X] = [A][X] + [Y]; \qquad (1)$$

where:

$[X]$ = a vector of total gross sector output (from table 1),
$[Y]$ = vector of final demands for sector goods and services (from table 1), and
$[A]$ = a matrix of direct coefficients (from table 2).

Table 2--Direct coefficient matrix showing proportion of total expenditures by sector, Douglas County, Oregon, 1970

Local disbursing sector	Local purchasing sector		
	Wood products	Trade and services	Other local industries
Wood products	0.0903	0.0009	0.0334
Trade and services	.0924	.0703	.0927
Other local industries	.1543	.0511	.1151
Total purchases	.3370	.1223	.2412
Primary input	.6630	.8777	.7588
Total input	1.0000	1.0000	1.0000

Equation (1) must be rearranged when used in making predictions so that it represents a relationship between gross output and final demands:

$$[X] - [A][X] = [Y]; \tag{2}$$

and the equivalent form:

$$[X]\,[I - A] = [Y]; \tag{3}$$

where [I] is an identity matrix; that is, 1's on the diagonal in the matrix and 0's elsewhere.

The final step is to invert the [I - A] matrix (see table 3). This step yields the demand multipliers for predicting the effects of a change in final demand on gross output. Thus, forecasted gross output depends on the interindustry structure of the local economy, represented by demand multipliers, and its final demands.

Interindustry purchases are derived simply by multiplying each sector's direct input requirements by its total purchases, which are exactly equal to its gross output:

[Gross output] = [final demand multipliers] [final demands].

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Table 3--Direct and indirect coefficient matrix showing change in sales associated with a $1-change in sales to final demand, Douglas County, Oregon, 1970

Purchasing sector	Disbursing sector		
	Wood products	Trade and services	Other local industries
Wood products	1.10672	0.00328	0.04213
Trade and services	.12999	1.08235	.11826
Other local industries	.20055	.06322	1.14432
Total	1.43726	1.14885	1.30471

This relationship is derived directly from equation (3) by rearranging the output-related variables:

$$[X] = [I - A]^{-1} [Y]. \qquad (4)$$

The $[I - A]^{-1}$ matrix is commonly referred to as the "Leontief inverse." The column totals in table 3 represent the sector demand multipliers and show the change in sector output associated with a dollar change in sales to final (exogenous) demand. For example, if final demand for Douglas County wood products were to increase $500,000, total county output would increase $718,630 (the product of $500,000 and 1.43726). The Trade and Services sector has the smallest demand multiplier (1.14885) of the three sectors, attributed to a greater reliance on imports and primary inputs.

Leontief Inverse Links I/O and IPASS Models

The I/O model is a powerful economic tool. Nevertheless, it has several inherent features that limit its ability to forecast future events. The I/O model does not allow for time--the multiplier effects are assumed to take place within a given period of time, typically 1 year. The model provides no way to forecast changes in one final demand. Finally, the I/O model does not account for changes or constraints in investment, labor force, or population.

The IPASS model was designed to overcome the limitations in the I/O model. IPASS incorporates the industry demand multipliers, the Leontief inverse matrix, as its production module (fig. 2).

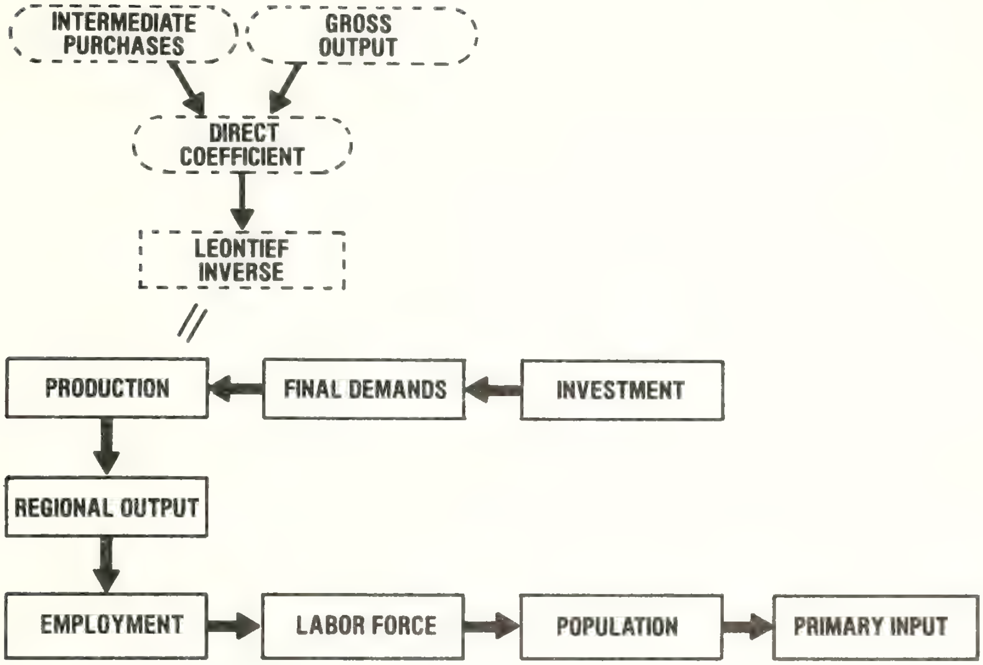

Figure 2.--Relationship between IPASS and the conventional I/O model. The Leontief inverse matrix $[I - A]^{-1}$ is the IPASS production module.

Synopsis of the IPASS Model

IPASS is a dynamic simulation model capable of forecasting a number of basic socioeconomic indicators (for example, population, employment, earnings, and investment) on an annual basis. Over 60 algorithms are used to calculate and project socioeconomic variables. The model proceeds step by step to derive sequentially related parameters. Hence, it is recursive: annual output derived from calculations becomes input for another annual iteration.

The IPASS model requires comprehensive data on the economic and social situation for the initial year. This data base includes statistics on employment, population, earnings, productivity, and output; annual rates of change for a large number of variables such as birth rates; and hours worked per week. Using the data base and historical rates of change, IPASS will simulate the growth and development of an economy for a specified interval of time. Such a forecast is called a "baseline analysis" and serves to calibrate forecasts based on alternative, nonhistorical assumptions. The user can, for example, create an alternative situation by changing one or more parameters in the data base for any year during the specified time period. An alternative situation might incorporate an increase in investment, or a combination of a change in population growth and increased worker productivity, for example. Changing a parameter would have an "impact" on the economy. The extent of the impact can be determined by comparing results of the alternative forecast to the baseline analysis. This "impact analysis" is an important quantitative tool for policy analysts, planners, researchers, and educators.

Using IPASS

Users need not know how the various components of IPASS work to conduct an impact analysis. Rather, users merely respond to a series of direct questions regarding their preferences for particular data outputs and related data inputs. Data outputs are the indicators of regional growth and change: population, employment, and income. Data inputs are the: (1) initial socioeconomic conditions, represented by the data outputs; and (2) relationships among these variables, or parameters, that represent the interindustry structure of the local economy.

To demonstrate the use of IPASS, we will give two examples based on data for Douglas County, Oregon. The first example will be a baseline analysis, which shows how the Douglas County economy would have performed had historical trends persisted during the forecast period. The second example will be an impact analysis, which compares the baseline performance with a forecast that reflects changes in several user-specified parameters.

Example 1: Baseline Analysis

The IPASS program prints a series of questions to which the user responds. In our example, question, data, and technical comments from IPASS are in capital letters; responses from the user are in lower case boldface.

Activate program

Assume you are logged onto the Cyber computer at Oregon State University and want to obtain the IPASS program. You must key the following commands:

```
attach,ipass
/ipass
```

These commands activate the IPASS program in interactive mode. Immediately IPASS asks which region you want to analyze by displaying:

```
(1) WELCOME TO IPASS
    UPDATE  17-JAN-84  --  VERSION 3.4
    WHAT REGION DO YOU WANT TO SIMULATE?
    TYPE IN THE NUMBER WHICH REPRESENTS THAT REGION.
     1 ... MINNESOTA (1970)
     2 ... DOUGLAS COUNTY, OREGON (1972)
     3 ... ALASKA (1977)
     4 ... S.E. ALASKA (1977)
    25 ... OTHERS
  ?
```

After answering an IPASS question, the user must press either the "return" or "enter" key to complete a response. IPASS can wait for about 10 minutes for your complete response; further idle time will cause the computer to disconnect you.

Since we want to simulate the Douglas County economy, a "2" is the appropriate response:

```
2
THE REGION IS DOUGLAS CNTY, OREGON
```

Note that IPASS verifies your choice, "The region is Douglas Cnty, Oregon. Caution: Select the desired region carefully because once the "return" key has been pressed, the only way to correct an error is to start the simulation over. Appendix D provides advice on ways to avoid this type of error and similar kinds of errors.

Specify format

```
(2) DOES YOUR TERMINAL PRINT 80 OR 132 CHARACTERS PER LINE?
    TYPE [80 OR 132]
  ? 132
    132
```

The 132-character format is preferable because IPASS prints wide tables of data, but the same information can be provided in 80-character format. Again, note that IPASS verifies your response.

```
(3) WHICH ANNUAL SUMMARY TABLE DO YOU WANT TO FOLLOW?
    TYPE ONE NUMBER [0-6]
  ? 6
      6
```

IPASS can generate a large amount of information based on annual statistics, not all of which is needed to gage the performance of the economy being simulated. Annual summary tables display totals of key indicators, which give the user a view of the region's economic performance. Depending on the user's main interest, one of the six annual summary tables may be selected. A description and example of each table is shown in appendix A. The user's choices are:

0 = no table
1 = market indicators
2 = final demand indicators
3 = investment indicators
4 = occupational employment
5 = labor force indicators
6 = general economic indicators.

For example, we are interested in a general overview of the performance of Douglas County's economy, so we have selected annual summary table 6.

Summary tables provide only gross totals. But additional information regarding individual sectors, occupation, and age classes could be obtained by responding with a "yes" to the next question:

```
(4) DO YOU WANT TO SEE THE 1972 DATA TABLES?
    [YES OR NO]
  ? no
    N
```

For the baseline analysis, we forgo the additional information. In example 2, however, we will explore this question in more detail.

Taking the first opportunity to edit data base

```
(5) DO YOU WANT TO MODIFY THE ORIGINAL DATA BASE?
    [YES OR NO]
  ? no
    N
```

If part of the data provided by the computer files does not fit the user's needs, the user can change parameters rather than create an entire data base.
To keep the modified data base, the user may simulate 0 years (answer "0" to question 7) and create a permanent file containing the data base with the user's changes by answering "yes" to question 14.

Responding "yes" to question 5 puts the user into the parameter change routine discussed in example 2, question 11.

The next question is for the more experienced user who wants to introduce change in IPASS's basic computational procedures. (These procedures will be published in another manual.)

```
(6) DO YOU WANT TO USE OPTIONAL IPASS PROGRAMMING?
    [YES OR NO]
  ? no
    N
```

Tell IPASS when to stop simulation

```
(7) HOW MANY YEARS DO YOU WANT TO SIMULATE?
  ? 3
       3
```

For this example, we need a minimum of 3 years to simulate the impact of the change that will be introduced in example 2. With a shorter time period, baseline trends could wash out the inputs of the change resulting from a parameter change.

```
(8) HOW FREQUENTLY DO YOU WANT TO VIEW DATA TABLES?
  ? 0
       0
```

Question 4 gave us an opportunity to view the original (1972) data tables. The user may now request opportunities to view the data tables during the simulation. Possible user responses to question 8 are:

0 = No opportunity to see data tables during simulation.
1 = Opportunity to view tables for each year of simulation.
2 = Opportunity to view tables every other year of simulation (for example, years 2,4,6...).
3 = Opportunity to view tables every third year of simulation (for example, years 3,6,9...).
n = Opportunity to view tables every nth year of simulation (for example, years n,2n,3n...).

No matter what the response is to question 8, the user will have a chance to view the data tables after the final year of simulation. For our baseline analysis, we do not need to see the data tables during the simulation, so our response is "0."

```
(9) HOW FREQUENTLY DO YOU WANT TO MODIFY THE SIMULATION?
  ? 0
     0
```

Users can indicate how frequently they want to modify parameters during the simulation. Possible responses are shown below. Note that all opportunities allow users to modify parameters for the 1st year of the simulation.

0 = Opportunity to modify only the 1st year of simulation.
1 = Opportunity to modify each year of simulation.
2 = Opportunity to modify the 1st, 3rd, and every other year thereafter.
3 = Opportunity to modify the 1st, 4th, and every 3rd year thereafter.
n = Opportunity to modify the 1st, n+1, and every nth year thereafter.

For our example, we respond with a "0."

```
---------------------------------------------------------------------------------------------------------
 SUMMARY TABLE OF GENERAL ECONOMIC INDICATORS,
 DOUGLAS CNTY, OREGON 1972-1975.
----------------------------------------------------------------------------------------------------------
                                                                     EARNINGS                LABOR    TOTAL
                POPU    EMPLOY         UN     GROSS                     PER       LOCAL      FORCE    LABOR
 YEAR          LATION    MENT     EMPLOYED  OUTPUT    EXPORT      PCE    PERSON    DEMAND      RATE    FORCE
----------------------------------------------------------------------------------------------------------
               (THOU)   (THOU)    (THOU)    (MILL)    (MILL)    (MILL)    (NO.)    (MILL)     (PCT)   (THOU)
 1972            81.      25.6       5.1      703.     309.0     180.3    2028.    217.6     54.061   30.708
```

IPASS prints data requested

Above is the annual summary table of general economic indicators requested by the user's response to question 3. PCE stands for personal consumption expenditures, or total annual expenditures by members of households. Local demand is the quantity of finished goods and services purchased by users within the local economy and excludes exported goods and services. The labor force rate is the percentage of residents over 16 years old who are gainfully employed or are seeking employment.

```
(10) DO YOU WANT TO MODIFY THE 1973 SIMULATION?
     [YES OR NO]
   ? no
     N
```

For the baseline analysis, we do not want to change the parameters. In example 2 we will introduce a change.

```
(11) DO YOU WANT TO MODIFY "SPECIAL" INVESTMENT PARAMETERS
     FOR 1973?
     [YES OR NO]
   ? no
     N
```

```
(12) DO YOU WANT TO MODIFY "SPECIAL" FINAL DEMAND PARAMETERS
     FOR 1973?
     [YES OR NO]
   ? no
     N
```

For the baseline analysis, we do not want to change special parameters. The special parameters are discussed in example 2.

Final year of simulation concludes

```
----------------------------------------------------------------------------------------------------------------
SUMMARY TABLE OF GENERAL ECONOMIC INDICATORS,
DOUGLAS CNTY, OREGON 1973-1975.
----------------------------------------------------------------------------------------------------------------
                                                                          EARNINGS               LABOR     TOTAL
                POPU     EMPLOY         UN     GROSS                           PER     LOCAL     FORCE     LABOR
YEAR          LATION       MENT   EMPLOYED    OUTPUT    EXPORT       PCE    PERSON    DEMAND      RATE     FORCE
----------------------------------------------------------------------------------------------------------------
              (THOU)     (THOU)     (THOU)    (MILL)    (MILL)    (MILL)     (NO.)    (MILL)     (PCT)    (THOU)
1973             81.       26.6        4.7      740.     323.3     177.8     2099.     232.4    54.141    31.316
PCT               .6        4.0       -8.2       5.3       4.6      -1.4       3.5       6.8        .1       2.0
1974             82.       27.5        4.4      775.     351.5     177.8     2157.     231.6    54.322    31.988
PCT               .8        3.4       -5.4       4.8       8.7        .0       2.8       -.3        .3       2.1
1975             82.       27.9        4.8      793.     370.7     178.4     2176.     225.8    54.657    32.684
PCT               .7        1.3        8.0       2.3       5.5        .3        .9      -2.5        .6       2.2
PCTB            2.13       8.96      -6.21     12.77     19.97     -1.09      7.27      3.73      1.10      6.44
APCB             .71       2.90      -2.11      4.09      6.26      -.37      2.37      1.23       .37      2.10
----------------------------------------------------------------------------------------------------------------
PCT ...PERCENTAGE CHANGE RELATIVE TO PREVIOUS YEAR
PCTB ...PERCENTAGE CHANGE RELATIVE TO BASE YEAR
APCB ...ANNUAL PERCENTAGE CHANGE RELATIVE TO BASE YEAR
```

```
(13) YEAR  1975 HAS BEEN REACHED.
     DO YOU WANT TO SEE THE NEW DATA TABLES?
     [YES OR NO]
    ? no
     N
```

To keep the baseline projection simple, we will forgo having IPASS print out detailed data.

Saving projections for later analysis

```
(14) SAVE 1975 DATA BASE FOR FUTURE USE?
    ? no
     N
```

The user may want to use the data base from the final year of simulation in a later analysis. By saving the data base at this time, the user may continue the simulation without having to recreate the 1975 data base. We have no need to save the data base for our example, so we answer "no."

For those who want more

```
(15) CONTINUE SIMULATION?
    ? no
     N
     IT HAS BEEN A PLEASURE TO WORK WITH YOU.
     HAVE A NICE DAY.
```

We answer "no" because we have completed the baseline analysis. If we had answered "yes," IPASS would have started over, beginning with question 6, using the data projected for 1975 rather than the original 1972 data base.

Example 2: Impact Analysis

Periodically, a firm must replace equipment to maintain production levels. Some equipment may simply wear out, whereas other equipment becomes outmoded. Furthermore, investment in equipment is needed to increase production. But what would happen to employment, gross regional output, and population if owners did not reinvest? Such a situation might prevail in Douglas County, Oregon, where dwindling timber supplies discourage investment in the lumber and wood products sectors. We will simulate this hypothetical situation using the 1972 Douglas County data base. By comparing the results with the baseline analysis conducted in example 1, we can assess the economic impact of constraining investment. All relevant questions and discussion from example 1 are repeated here for the user's convenience.

The IPASS program prints a series of questions to which the user responds. In our example, questions, data, and technical comments from IPASS are in captial letters; responses from the user are in lower case boldface.

Activate program

Assume you are logged onto the Cyber computer at Oregon State University and want to obtain the IPASS program. You must key the following commands:

```
attach,ipass
/ipass
```

These commands activate the IPASS program in interactive mode. Immediately IPASS asks which region you want to analyze:

```
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    WHAT REGION DO YOU WANT TO SIMULATE?
    TYPE THE NUMBER WHICH REPRESENTS THAT REGION.
     1 ... MINNESOTA (1970)
     2 ... DOUGLAS COUNTY, OREGON (1972)
     3 ... ALASKA (1977)
     4 ... S.E. ALASKA (1977)
    25 ... OTHERS
   ?
```

After answering an IPASS question, the user must press either the "return" or "enter" key to complete a response. IPASS will wait for about 10 minutes for your complete response; further idle time will cause the computer to disconnect you.

Since we want to simulate the Douglas County economy, a "2" is the appropriate response:

```
2
THE REGION IS DOUGLAS CNTY, OREGON
```

Note that IPASS verifies your choice, "The region is Douglas Cnty, Oregon." Caution: select the desired region carefully because once the "return" key has been pressed, the only way to correct an error is to start the simulation over. Appendix D provides advice on ways to avoid this type of error and similar kinds of errors.

Specify format

```
(2) DOES YOUR TERMINAL PRINT 80 OR 132 CHARACTERS PER LINE?
    TYPE [80 OR 132]
  ? 132
    132
```

The 132-character format is preferable because IPASS prints wide tables of data, but the same information can be provided in 80-character format. Again, note that IPASS verifies your response.

```
(3) WHICH ANNUAL SUMMARY TABLE DO YOU WANT TO FOLLOW?
    TYPE ONE NUMBER [0-6]
  ? 6
     6
```

IPASS can generate a large amount of information based on annual statistics, not all of which is needed to gage the performance of the economy being simulated. Annual summary tables display totals of key indicators, which give the user a view of the region's economic performance. Depending on the user's main interest, one of the six annual summary tables may be selected. A description and example of each table is shown in appendix A. The user's choices are:

0 = no table
1 = market indicators
2 = final demand indicators
3 = investment indicators
4 = occupational employment
5 = labor force indicators
6 = general economic indicators.

As we did in example 1, we request table 6. By comparing table 6 from the two analyses, we can determine impacts of our hypothetical situation--restricting investment in the lumber and wood products sectors.

Request data tables

The summary tables merely provide gross totals. To analyze investment trends in a particular sector, we will need more information than gross totals. More information would also be needed in analyses of population, occupational employment, and exports. Additional information can be obtained by responding with a "yes" to the next IPASS question:

```
(4) DO YOU WANT TO SEE THE 1972 DATA TABLES?
    [YES OR NO]
  ? yes
    Y
```

```
(5) WHAT TABLES DO YOU WANT TO SEE?
    TYPE NUMBERS [1-8]
  ? 1,3
    1,3
```

We have the choice of any or all of the following tables. A description and example of each is in appendix A.

1 = export market indicators
2 = intermediate and final demand indicators
3 = investment and capital stock indicators
4 = intermediate purchases, imports, and value-added indicators
5 = output, earnings, and employee compensation
6 = employment and unemployment
7 = total population and labor force indicators
8 = productivity indicators.

We have selected data tables 1 and 3. Data table 1 will permit us to trace the effects of investment changes in the wood products sector on other local industries. Data table 3 will identify specific investment changes by sector.

TABLE 1. EXPORT MARKET INDICATORS OF SPECIFIED SECTORS,
DOUGLAS CNTY, OREGON, 1972.

SECTOR		GROSS OUTPUT		ACTUAL MARKET SHARE			POTENTIAL MARKET SHARE	
NO.	TITLE	UNITED STATES	TOTAL REGION	REGIONAL EXPORT	PERCENT OF U.S. GROSS OUTPUT	ANNUAL CHANGE	EXPORTS	PERCENT OF U.S. GROSS OUTPUT
		(THOU)	(THOU)	(THOU)	(PERCENT)	(PERCENT)	(THOU)	(PERCENT)
1	LOGGING	3447545.	41795.	18906.	.5484	.0000	19582.	.5680
2	SAWMILLS	4493815.	43215.	40908.	.9103	.0000	40908.	.9103
3	PLY&VENEER	2329338.	137520.	131562.	5.6480	.0000	138785.	5.9581
4	FIBER PROD	26360411.	41794.	41876.	.1589	.0000	42308.	.1605
5	FISHING	4777643.	4202.	236.	.0049	.0000	270.	.0056
6	CROPS	31339156.	3505.	3206.	.0102	.0000	3334.	.0106
7	LIVESTOCK	36537238.	5488.	4324.	.0118	.0000	4324.	.0118
8	MANUFACTUR	413504121.	48406.	42023.	.0102	.0000	42686.	.0103
9	LODGING	8290052.	3826.	1907.	.0230	.0000	2144.	.0259
10	EATERIES	43882706.	9279.	657.	.0015	.0000	1398.	.0032
11	SERV STA	6295169.	20104.	3946.	.0627	.0000	5097.	.0810
12	CAR DEALER	14688960.	44693.	1327.	.0090	.0000	4034.	.0275
13	COM,TRAN,U	159188514.	25502.	438.	.0003	.0000	2740.	.0017
14	PROF SERV	84429033.	11832.	-354.	-.0004	.0000	1318.	.0016
15	FINANCIAL	31574623.	26270.	2161.	.0068	.0000	2846.	.0090
16	CONSTRUCT	146778672.	26610.	-1169.	-.0008	.0000	1399.	.0010
17	TRADE	149693686.	85934.	207.	.0001	.0000	6945.	.0046
18	RET SERV	197744310.	29321.	6411.	.0032	.0000	8179.	.0041
19	USFS SALES	10000.	17182.	6139.	61.3927	.0000	6139.	61.3927
20	BLM SALES	10000.	17465.	1873.	18.7274	.0000	1884.	18.8390
21	USFS APPRO	0.	9690.	0.	.0000	.0000	0.	.0000
22	BLM APPRO	0.	1713.	0.	.0000	.0000	0.	.0000
23	CNTY GOVT	2000.	33193.	1782.	89.0871	.0000	1782.	89.0871
24	CITY GOVT	1000.	4272.	665.	66.5073	.0000	665.	66.5073
25	ADMIN GOVT	100000.	10292.	0.	.0000	.0000	0.	.0000
	TOTAL	1365477992.	703102.	309032.	.0000	.0000	338768.	.0000

Interpret data table 1

There are 25 sectors in the Douglas County model. Gross output of the United States is the total for only those U.S. sectors that exist in Douglas County. U.S. gross output for sectors 19-25 are not generally available in other data sources, so numbers were "created" to satisfy model requirements. Negative values under "regional exports" result because sector capacity could not meet local demands; hence, negative values can be considered imports. When these values become highly negative, the user may consider modifying the Leontief inverse to more accurately represent the higher level of imports.

The difference between potential market share and actual market share is that actual market share reflects constraints on sector output by physical capacity and/or insufficient staffing. These constraints are relieved through investment in production equipment and by bringing in workers from the outside (in-migration).

Because 1972 is the initial year, there is no annual change in actual market share.

```
----------------------------------------------------------------------------------------------------------------
TABLE 3.  INVESTMENT AND CAPITAL STOCK INDICATORS OF SPECIFIED SECTORS,
          DOUGLAS CNTY, OREGON, 1972.
----------------------------------------------------------------------------------------------------------------
                            PRODUCTION                POLLUTION ABATEMENT                CAPITAL STOCK
     SECTOR        ----------------------------  -----------------------------  --------------------------------
--------------                REPLACE                        REPLACE                        POLLUTION
NO.   NAME        EXPANSION      MENT     TOTAL  EXPANSION      MENT     TOTAL  PRODUCTION  ABATEMENT      TOTAL
----------------------------------------------------------------------------------------------------------------
                     (THOU)    (THOU)    (THOU)     (THOU)    (THOU)    (THOU)      (THOU)     (THOU)     (THOU)
 1  LOGGING              0.      882.      882.         0.        0.        0.     16127.0         .0    16127.0
 2  SAWMILLS             0.     1390.     1390.         0.        0.        0.     29500.0         .0    29500.0
 3  PLY&VENEER         102.     2282.     2384.         6.      123.      129.     48094.0     2591.0    50685.0
 4  FIBER PROD           0.     1588.     1588.         0.       86.       86.     35360.0     1905.0    37265.0
 5  FISHING              0.       94.       94.         0.        0.        0.      3665.0         .0     3665.0
 6  CROPS                0.        0.        0.         0.        0.        0.      3034.0         .0     3034.0
 7  LIVESTOCK            0.        0.        0.         0.        0.        0.      4921.0         .0     4921.0
 8  MANUFACTUR           0.        3.        3.         0.        0.        0.     21014.0     1132.0    22146.0
 9  LODGING              0.        0.        0.         0.        0.        0.      1521.0         .0     1521.0
10  EATERIES             0.        0.        0.         0.        0.        0.      5261.0         .0     5261.0
11  SERV STA             0.        1.        1.         0.        0.        0.      8002.0         .0     8002.0
12  CAR DEALER           0.      183.      183.         0.        0.        0.     17793.0         .0    17793.0
13  COM,TRAN,U        1795.        1.     1796.         4.        0.        4.     34821.0       77.0    34898.0
14  PROF SERV           67.        0.       67.         0.        0.        0.      4707.0         .0     4707.0
15  FINANCIAL            0.        0.        0.         0.        0.        0.     10490.0         .0    10490.0
16  CONSTRUCT          863.        1.      864.         0.        0.        0.     24336.0         .0    24336.0
17  TRADE                0.        2.        2.         0.        0.        0.     60340.0         .0    60340.0
18  RET SERV             0.        0.        0.         0.        0.        0.     11682.0         .0    11682.0
19  USFS SALES           0.        0.        0.         0.        0.        0.     18000.0         .0    18000.0
20  BLM SALES            0.        0.        0.         0.        0.        0.     18000.0         .0    18000.0
21  USFS APPRO           0.        0.        0.         0.        0.        0.          .0         .0         .0
22  BLM APPRO            0.        0.        0.         0.        0.        0.          .0         .0         .0
23  CNTY GOVT            0.        0.        0.         0.        0.        0.          .0         .0         .0
24  CITY GOVT            0.        0.        0.         0.        0.        0.          .0         .0         .0
25  ADMIN GOVT           0.        0.        0.         0.        0.        0.          .0         .0         .0
    TOTAL             2827.     6427.     9254.        10.      209.      219.    376668.0     5705.0   382373.0
----------------------------------------------------------------------------------------------------------------
```

Interpret data table 3

Note the following identity:

$$S_t = S_{t-1} + EI_t + RI_t - D_t,$$

where:

S_t = capital stock in year "t,"

S_{t-1} = capital stock in year "t-1,"

EI_t = expansion investment in year "t,"

RI_t = replacement investment in year "t," and

D_t = depreciation in year "t."

Investment for production expansion is triggered when demand is greater than physical capacity (indicated by potential exports being greater than actual exports in data table 1). When depreciation occurs, productive capacity declines. If capacity falls below demand, investment is triggered to replace depreciated equipment. Capital stock is composed of "production" and "pollution abatement" equipment. If a sector can meet demands with available capital stock (S_{t-1}) for its products, there will be no investment. Also, there will be no investment if a sector has no cash to finance the investment. Finally, zeros may appear in under investment columns if amounts are less than $50.

Taking the first opportunity to edit data base

```
(6) DO YOU WANT TO MODIFY THE ORIGINAL DATA BASE?
    [YES OR NO]
   ? no
    N
```

If part of the data provided by the computer files does not fit the user's needs, the user can change parameters rather than create an entire data base. To keep this modified data base, the user may simulate 0 years (answer "0" to question 7) and create a permanent file containing the data base with the user's changes by answering "yes" to question 14.

Responding "yes" to question 6 puts the user into the parameter change routine as discussed in question 11 of example 2.

The next question is for the more experienced user who wants to introduce change in IPASS's basic computational procedures. (These procedures will be published in another manual.) We respond with "no."

```
(7) DO YOU WANT TO USE OPTIONAL IPASS PROGRAMMING?
    [YES OR NO]
  ? no
    N
```

Tell IPASS when to stop simulation

```
(8) HOW MANY YEARS DO YOU WANT TO SIMULATE?
  ? 3
       3
```

As with the baseline analysis, we request a 3-year simulation.

```
(9) HOW FREQUENTLY DO YOU WANT TO VIEW DATA TABLES?
  ? 1
       1
```

Question 4 gave us an opportunity to view the original (1972) data tables. The user may now request opportunities to view the data tables during the simulation. Possible user responses to question 9 are:

0 = No opportunity to see data tables during simulation.
1 = Opportunity to view tables for each year of simulation.
2 = Opportunity to view tables every other year of simulation (for example, years 3,6,9...).
3 = Opportunity to view tables every third year of simulation (for example, years 3,6,9...).
n = Opportunity to view tables every nth year of simulation (for example, years n,2n,3n...).

No matter what the response is to question 9, the user will have a chance to view the data tables after the final year of simulation.

We respond with a "1" because we want to see the data table for each year.

```
(10) HOW FREQUENTLY DO YOU WANT TO MODIFY THE SIMULATION?
   ? 0
        0
```

Users can indicate how frequently they want to modify parameters during the simulation. Possible responses are shown below. Note that all opportunities allow the user to modify parameters for the 1st year of the simulation.

0 = Opportunity to modify only the 1st year of simulation.
1 = Opportunity to modify each year of simulation.
2 = Opportunity to modify the 1st, 3d, and every other year thereafter.
3 = Opportunity to modify the 1st, 4th, and every 3d year thereafter.
n = Opportunity to modify the 1st, n + 1, and every nth year thereafter.

Our modifications of the investment limits will be permanent; that is, until we modify again, they will remain zero. In this example, we will have no further need to modify parameters.

IPASS prints data requested

```
----------------------------------------------------------------------------------------------------------------
SUMMARY TABLE OF GENERAL ECONOMIC INDICATORS,
DOUGLAS CNTY, OREGON 1972-1975.
----------------------------------------------------------------------------------------------------------------
                                                                        EARNINGS                LABOR    TOTAL
               POPU    EMPLOY       UN      GROSS                         PER       LOCAL       FORCE    LABOR
YEAR           LATION  MENT      EMPLOYED  OUTPUT    EXPORT     PCE      PERSON     DEMAND       RATE    FORCE
----------------------------------------------------------------------------------------------------------------
             (THOU)    (THOU)    (THOU)    (MILL)    (MILL)    (MILL)     (NO.)     (MILL)     (PCT)     (THOU)
1972            81.      25.6       5.1      703.     309.0     180.3     2028.     217.6      54.061    30.708
```

Above is the annual summary table of general economic indicators requested by the user's response to question 3. PCE stands for personal consumption expenditures, or total annual expenditures by members of households. Local demand is the quantity of finished goods and services purchased by users within the local economy and excludes exported goods and services. The labor force rate is the percentage of residents over 16 years old who are gainfully employed or are seeking employment.

Modifying the baseline analysis

A fundamental strength of IPASS is its flexibility; the user may change any or all of the 120 parameters in the data base. All parameters are listed in appendix C, table 5.

In example 2, we will change investment parameters. During the sequence of calculations for 1 year of simulation, the user has three opportunities to modify parameters (fig. 3). Changes to some investment and final demand parameters (identified as "special" parameters in table 5, appendix C) must be introduced after the simulation year commences. Changes in the remaining parameters must be introduced before the simulation year begins.

```
(11) DO YOU WANT TO MODIFY THE 1973 SIMULATION?
     [YES OR NO]
   ? yes
     Y
```

```
(12) WHAT PARAMETERS DO YOU WANT TO MODIFY?
     TYPE UP TO TEN NUMBERS [1-120]
   ? 15,16
     15,16
```

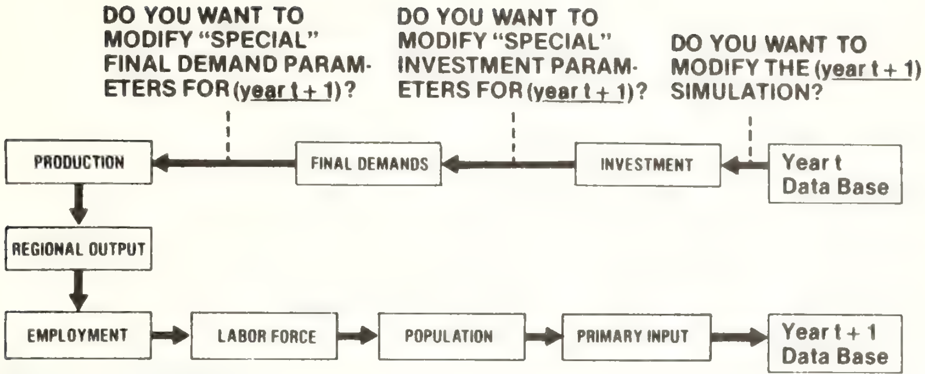

DO YOU WANT TO MODIFY "SPECIAL" FINAL DEMAND PARAMETERS FOR (year t + 1)?
DO YOU WANT TO MODIFY "SPECIAL" INVESTMENT PARAMETERS FOR (year t + 1)?
DO YOU WANT TO MODIFY THE (year t + 1) SIMULATION?
PRODUCTION
FINAL DEMANDS
INVESTMENT
Year t Data Base
REGIONAL OUTPUT
EMPLOYMENT
LABOR FORCE
POPULATION
PRIMARY INPUT
Year t + 1 Data Base

Figure 3.--Opportunities for changing parameters in the IPASS sequence.

We want to modify the baseline analysis to reflect the decision not to invest made by the wood products sector. To change the level of investment by the wood products sector, we must modify two parameters: leverage ratio, and liquidity preference ratio. The leverage ratio reflects the sector's ability to generate capital. Liquidity preference ratio expresses the sector's willingness to borrow. Both parameters must be set equal to zero to reflect no investments. Looking down the parameter list (table 5, appendix C), we find "leverage ratio" (parameter 15) and "liquidity preference ratio" (parameter 16). Neither are "special" parameters.

```
(13) HOW DO YOU WANT TO MODIFY
       15:  LEVERAGE RATIO
     ?
```

Our response is a 4-part code that sets up the modification:

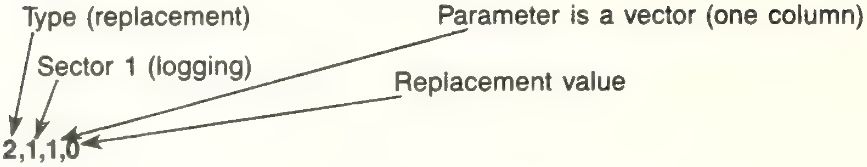
(1) Type of parameter modification: Specifies the types of modification. Table 4, appendix B, provides a list of types. In our example, we want to replace current values for the "leverage ratio," so we select type "2."

(2) Sector affected: Identifies the sector for which modifications are to be made. Data table 1 (page 15), lists the sectors of the Douglas County model. We want to change the leverage ratio for the four wood products sectors (logging, sawmills, veneer and plywood, and fiber products). The user can only identify one element at a time, however, so we will start with sector 1, "logging."

(3) Vector or matrix change: Indicates the dimension of the parameter being changed. If the change involves a matrix, code the number of the column in which the modification is being made. Figure 5, appendix B, illustrates a vector and matrix. The list of parameters (table 5, appendix C) will help users determine the dimensions of the parameter they want to change. In our example, the modification involves a vector, so we code "1."

(4) New value: States the modification. We want to indicate no investment, so our new value is "0."

A complete response for the logging sector is:



```
  2,1,1,0
 2,1,1,0
 SECTOR  1, 1  WAS ...       13.00000   IS ...         .00000
?
```

IPASS provides another prompt ("?"), signifying that the user can continue to modify parameter 15 for other sectors. In our example, three additional responses are required to change current leverage ratios to zero for sawmills (sector 2), plywood and veneer (sector 3), and fiber products (sector 4).

```
  2,2,1,0
 2,2,1,0
 SECTOR  2, 1  WAS ...       13.00000   IS ...         .00000
? 2,3,1,0
 2,3,1,0
 SECTOR  3, 1  WAS ...       13.00000   IS ...         .00000
? 2,4,1,0
 2,4,1,0
 SECTOR  4, 1  WAS ...       13.00000   IS ...         .00000
? 0
 0
```

We are now finished modifying this parameter, so we respond with parameter option "0."

```
(14) HOW DO YOU WANT TO MODIFY
     16:  LIQUIDITY PREFERENCE RATIO
```

IPASS automatically proceeds to parameter 16, the second parameter we want to change (see question 12). As with parameter 15, the values are changed to zero:

```
? 2,1,1,0 0
 2,1,1,0
 SECTOR  1, 1  WAS ...          .50000   IS ...         .00000
? 2,2,1,0 0
 2,2,1,0
 SECTOR  2, 1  WAS ...          .50000   IS ...         .00000
? 2,3,1,0 0
 2,3,1,0
 SECTOR  3, 1  WAS ...          .50000   IS ...         .00000
? 2,4,1,0 0
 2,4,1,0
 SECTOR  4, 1  WAS ...          .50000   IS ...         .00000
? 0
 0
```

```
(15) DO YOU WANT TO MAKE ANY OTHER PARAMETER MODIFICATIONS?
     [YES OR NO]
   ? no
     N
```

In question 12, IPASS limited the user to 10 parameter changes (this saves memory space). IPASS will now accomodate more parameter changes if needed. Because we do not want to modify any other parameters, we say "no."

```
(16) DO YOU WANT TO MODIFY "SPECIAL" INVESTMENT PARAMETERS
     FOR 1973?
     [YES OR NO]
   ? no
     N

(17) DO YOU WANT TO MODIFY "SPECIAL" FINAL DEMAND PARAMETERS
     FOR 1973?
     [YES OR NO]
   ? no
     N
```

Earlier we assumed the wood products sectors would not invest during the entire simulation period. Had we wanted to single out a particular year for modifying investment, however, we would do it now using the procedure for changing parameters outlined in appendix B.

First year of simulation concludes

All calculations for the first year of the simulation have been completed when IPASS automatically displays the annual summary table for 1973. The PCT row is the percentage change relative to the previous year.

```
---------------------------------------------------------------------------------------------------
SUMMARY TABLE OF GENERAL ECONOMIC INDICATORS,
DOUGLAS CNTY, OREGON 1973-1975.
---------------------------------------------------------------------------------------------------
                                                                   EARNINGS              LABOR   TOTAL
              POPU    EMPLOY       UN     GROSS                      PER      LOCAL     FORCE    LABOR
YEAR         LATION    MENT    EMPLOYED  OUTPUT   EXPORT     PCE    PERSON    DEMAND     RATE    FORCE
---------------------------------------------------------------------------------------------------
             (THOU)   (THOU)    (THOU)   (MILL)   (MILL)   (MILL)    (NO.)    (MILL)    (PCT)   (THOU)
1973            81.     25.8       5.5     713.    308.4    177.8    2022.     228.8   54.149   31.307
PCT              .6       .7       8.3      1.4      -.2     -1.4      -.3       5.1       .2      2.0
```

IPASS now gives us an opportunity to view the 1973 data tables. We may want to trace the effects of investment changes in the wood products sectors on the output of other sectors, so we respond with a "yes."

```
(18) DO YOU WANT TO SEE THE 1973 DATA TABLES?
     [YES OR NO]
   ? yes
     Y

(19) WHAT TABLES DO YOU WANT TO SEE?
     TYPE NUMBERS [1-8]
   ? 1,3
     1,3
```

We have asked for data table 1 to trace the impact of the changes to investment on the Douglas County economy.

```
-------------------------------------------------------------------------------------------------------------------
TABLE 1.  EXPORT MARKET INDICATORS OF SPECIFIED SECTORS,
          DOUGLAS CNTY, OREGON, 1973.
-------------------------------------------------------------------------------------------------------------------
                                 GROSS OUTPUT                  ACTUAL MARKET SHARE              POTENTIAL MARKET SHARE
                            ----------------------   ------------------------------------   ------------------------
    SECTOR                                                         PERCENT                                 PERCENT
-------------                 UNITED        TOTAL     REGIONAL     OF U.S.        ANNUAL                   OF U.S.
NO.   TITLE                   STATES       REGION      EXPORT    GROSS OUTPUT     CHANGE       EXPORTS   GROSS OUTPUT
-------------------------------------------------------------------------------------------------------------------
                              (THOU)       (THOU)      (THOU)     (PERCENT)     (PERCENT)      (THOU)     (PERCENT)
 1  LOGGING                 3593035.      38987.      16078.        .4475       -21.2169      20428.        .5686
 2  SAWMILLS                4576447.      42577.      39565.        .8645        -5.0291      41626.        .9096
 3  PLY&VENEER              2441635.     130612.     123897.       5.0743       -14.8335     146382.       5.9952
 4  FIBER PROD             27246912.      39778.      39492.        .1449        -9.6930      43731.        .1605
 5  FISHING                 4954301.       4217.        166.        .0033       -40.7330        280.        .0056
 6  CROPS                  32599930.       3638.       3329.        .0102        -4.0298       3468.        .0106
 7  LIVESTOCK              37149931.       5677.       4381.        .0118         -.3608       4397.        .0118
 8  MANUFACTUR            427499995.      49391.      41433.        .0097        -6.1136      44320.        .0104
 9  LODGING                 8448508.       4064.       2153.        .0255        -1.4517       2193.        .0260
10  EATERIES               44780371.       9925.       1427.        .0032          .0000       1427.        .0032
11  SERV STA                6581121.      21342.       5154.        .0783        -3.2629       5328.        .0810
12  CAR DEALER             15366606.      47682.       3218.        .0209       -23.7451       4225.        .0275
13  COM,TRAN,U            165293871.      28104.       2613.        .0016        -8.1441       2882.        .0017
14  PROF SERV              86907025.      13577.       1481.        .0017         9.1727       1788.        .0021
15  FINANCIAL              32733222.      26815.       2755.        .0084        -6.6187       2983.        .0091
16  CONSTRUCT             149044935.      29772.      -2055.       -.0014        -1.4468       1534.        .0010
17  TRADE                 155011554.      93393.       4966.        .0032       -30.9484       7918.        .0051
18  RET SERV              205764819.      31429.       8163.        .0040        -4.0887       8555.        .0042
19  USFS SALES                10000.      16619.       6073.      60.7329        -1.0746       6139.      61.3927
20  BLM SALES                 10000.      16522.       1623.      16.2300       -13.8489       1884.      18.8390
21  USFS APPRO                   0.       9745.          0.        .0000          .0000          0.        .0000
22  BLM APPRO                    0.       1723.          0.        .0000          .0000          0.        .0000
23  CNTY GOVT                  2000.      33005.       1782.      89.0871          .0000       1782.      89.0871
24  CITY GOVT                  1000.       4334.        665.      66.5073          .0000        665.      66.5073
25  ADMIN GOVT               100000.      10237.          0.        .0000          .0000          0.        .0000
    TOTAL                1410117218.     713166.     308360.        .0000          .0000     353934.        .0000
-------------------------------------------------------------------------------------------------------------------
```

The percentage annual change in U.S. gross output shows mostly negative values in data table 1 even though regional exports for 1973 are higher than those in 1972. The negative annual change resulted from U.S. gross output growing at even a faster rate than regional exports grew.

```
-------------------------------------------------------------------------------------------------------------
TABLE 3.  INVESTMENT AND CAPITAL STOCK INDICATORS OF SPECIFIED SECTORS,
          DOUGLAS CNTY, OREGON, 1973.
-------------------------------------------------------------------------------------------------------------
                                  PRODUCTION                POLLUTION ABATEMENT               CAPITAL STOCK
    SECTOR               ---------------------------   ---------------------------   ---------------------------
-------------                     REPLACE                       REPLACE                         POLLUTION
NO.     NAME            EXPANSION   MENT       TOTAL   EXPANSION   MENT       TOTAL   PRODUCTION ABATEMENT   TOTAL
-------------------------------------------------------------------------------------------------------------
                         (THOU)    (THOU)     (THOU)    (THOU)    (THOU)     (THOU)    (THOU)    (THOU)     (THOU)
 1  LOGGING                 0.        0.         0.        0.        0.         0.    15158.9       .0    15158.9
 2  SAWMILLS                0.        0.         0.        0.        0.         0.    27996.0       .0    27996.0
 3  PLY&VENEER              0.        0.         0.        0.        0.         0.    45682.2   2461.1    48143.2
 4  FIBER PROD              0.        0.         0.        0.        0.         0.    33654.6   1813.1    35467.8
 5  FISHING                75.      105.       180.        0.        0.         0.     3740.0       .0     3740.0
 6  CROPS                 115.        0.       115.        0.        0.         0.     3148.9       .0     3148.9
 7  LIVESTOCK               0.        0.         0.        0.        0.         0.     4921.0       .0     4921.0
 8  MANUFACTUR            416.        3.       418.       22.        0.        23.    21429.6   1154.4    22584.0
 9  LODGING                95.        0.        95.        0.        0.         0.     1615.5       .0     1615.5
10  EATERIES              421.        0.       421.        0.        0.         0.     5681.8       .0     5681.8
11  SERV STA              532.        1.       533.        0.        0.         0.     8533.6       .0     8533.7
12  CAR DEALER           1254.      194.      1448.        0.        0.         0.    19046.8       .0    19046.8
13  COM,TRAN,U           3840.        1.      3841.        9.        0.         9.    38660.9     85.5    38746.4
14  PROF SERV             694.        0.       694.        0.        0.         0.     5401.0       .0     5401.0
15  FINANCIAL             461.        0.       461.        0.        0.         0.    10950.7       .0    10950.7
16  CONSTRUCT            2988.        1.      2988.        0.        0.         0.    27323.8       .0    27323.9
17  TRADE                5322.        2.      5323.        0.        0.         0.    65661.6       .0    65661.6
18  RET SERV              840.        0.       840.        0.        0.         0.    12522.1       .0    12522.1
19  USFS SALES              0.        0.         0.        0.        0.         0.    18000.0       .0    18000.0
20  BLM SALES               0.        0.         0.        0.        0.         0.    18000.0       .0    18000.0
21  USFS APPRO              0.        0.         0.        0.        0.         0.         .0       .0         .0
22  BLM APPRO               0.        0.         0.        0.        0.         0.         .0       .0         .0
23  CNTY GOVT               0.        0.         0.        0.        0.         0.         .0       .0         .0
24  CITY GOVT               0.        0.         0.        0.        0.         0.         .0       .0         .0
25  ADMIN GOVT              0.        0.         0.        0.        0.         0.         .0       .0         .0
    TOTAL               17050.      308.     17358.       31.        0.        31.   387129.0   5514.1   392643.1
-------------------------------------------------------------------------------------------------------------
```

Data table 3 verifies with zeros that the four wood products sectors did not invest in production or pollution abatement in 1973.

Second year of simulation concludes

IPASS will automatically provide the summary table:

```
------------------------------------------------------------------------------------------------
SUMMARY TABLE OF GENERAL ECONOMIC INDICATORS,
DOUGLAS CNTY, OREGON 1974-1975.
------------------------------------------------------------------------------------------------
                                                            EARNINGS              LABOR   TOTAL
              POPU    EMPLOY      UN     GROSS                 PER      LOCAL     FORCE   LABOR
YEAR          LATION  MENT     EMPLOYED  OUTPUT  EXPORT   PCE  PERSON   DEMAND    RATE    FORCE
------------------------------------------------------------------------------------------------
              (THOU)  (THOU)   (THOU)   (MILL)  (MILL)  (MILL)  (NO.)   (MILL)    (PCT)   (THOU)
1974           82.    25.4      6.5     708.    313.3   178.0   1978.   222.5    54.370  31.936
PCT            .6     -1.4     17.8     -.7      1.6     .1     -2.2    -2.7       .4     2.0
```

Notice that 1974 gross output has dropped below 1973 levels. For that matter, nearly all indicators, except unemployment and exports, are below 1973 levels. The elimination of investment in the wood products sectors has perversly affected the local economy through its reduction in capital formation, reduction in capacity, and associated interindustry effects. The seemingly contradictory increase in exports is the result of the decline in local demand. The decline has freed capacity to supply outside demand.

We will again look at data tables 1 and 3:

```
(20) DO YOU WANT TO SEE THE 1974 DATA TABLES?
     [YES OR NO]
   ? yes
     Y

(21) WHAT TABLES DO YOU WANT TO SEE?
     TYPE NUMBERS [1-8]
   ? 1,3
     1,3
```

```
------------------------------------------------------------------------------------------------------
TABLE 1.  EXPORT MARKET INDICATORS OF SPECIFIED SECTORS,
          DOUGLAS CNTY, OREGON, 1974.
------------------------------------------------------------------------------------------------------
                          GROSS OUTPUT                 ACTUAL MARKET SHARE          POTENTIAL MARKET SHARE
                    ----------------------   ---------------------------------   ----------------------
    SECTOR                                                PERCENT                            PERCENT
---------------       UNITED       TOTAL      REGIONAL    OF U.S.       ANNUAL                OF U.S.
NO.  TITLE            STATES       REGION      EXPORT   GROSS OUTPUT    CHANGE     EXPORTS  GROSS OUTPUT
------------------------------------------------------------------------------------------------------
                      (THOU)       (THOU)      (THOU)    (PERCENT)    (PERCENT)    (THOU)    (PERCENT)
 1  LOGGING          3744665.      36338.      15377.       .4106     -27.7755     21311.       .5691
 2  SAWMILLS         4660599.      40311.      37825.       .8116     -10.7710     42357.       .9088
 3  PLY&VENEER       2559347.     124052.     119301.      4.6614     -22.2483    154394.      6.0326
 4  FIBER PROD      28163225.      37860.      38053.       .1351     -15.8163     45202.       .1605
 5  FISHING          5137491.       4526.        219.       .0043     -24.5401       290.       .0056
 6  CROPS           33911425.       3781.       3448.       .0102      -4.4240      3608.       .0106
 7  LIVESTOCK       37772898.       5720.       4378.       .0116      -2.0755      4471.       .0118
 8  MANUFACTUR     441969587.      52565.      44241.       .0100      -3.4476     46017.       .0104
 9  LODGING          8609993.       4106.       2204.       .0256      -1.3615      2243.       .0260
10  EATERIES        45696398.       9904.       1456.       .0032        .0000      1456.       .0032
11  SERV STA         6880062.      21700.       5485.       .0797      -1.5303      5570.       .0810
12  CAR DEALER      16075513.      48855.       4315.       .0268      -2.3661      4424.       .0275
13  COM,TRAN,U     171633387.      28369.       3007.       .0018        .4784      3032.       .0018
14  PROF SERV       89457746.      13955.       1841.       .0021        .0257      2426.       .0027
15  FINANCIAL       33934335.      26747.       3042.       .0090      -1.6371      3126.       .0092
16  CONSTRUCT      151346188.      30616.       1682.       .0011       8.0060      1682.       .0011
17  TRADE          160518340.      96580.       8852.       .0055       7.9610      9026.       .0056
18  RET SERV       214110640.      32087.       8701.       .0041      -2.2561      8948.       .0042
19  USFS SALES         10000.      15979.       5969.     59.6914      -2.7711      6139.     61.3927
20  BLM SALES          10000.      15595.       1495.     14.9513     -20.6363      1884.     18.8390
21  USFS APPRO             0.       9801.          0.       .0000        .0000         0.       .0000
22  BLM APPRO              0.       1733.          0.       .0000        .0000         0.       .0000
23  CNTY GOVT           2000.      32657.       1782.     89.0871        .0000      1782.     89.0871
24  CITY GOVT           1000.       4341.        665.     66.5073        .0000       665.     66.5073
25  ADMIN GOVT        100000.      10280.          0.       .0000        .0000         0.       .0000
    TOTAL         1456304840.     708459.     313338.       .0000        .0000    370053.       .0000
------------------------------------------------------------------------------------------------------
```

```
-----------------------------------------------------------------------------------------------------------------
TABLE 3.  INVESTMENT AND CAPITAL STOCK INDICATORS OF SPECIFIED SECTORS,
          DOUGLAS CNTY, OREGON, 1974.
-----------------------------------------------------------------------------------------------------------------
                                    PRODUCTION                  POLLUTION ABATEMENT             CAPITAL STOCK
     SECTOR              -----------------------------   -----------------------------  ------------------------------
--------------                       REPLACE                        REPLACE                      POLLUTION
NO.     NAME             EXPANSION    MENT       TOTAL   EXPANSION    MENT       TOTAL  PRODUCTION ABATEMENT    TOTAL
-----------------------------------------------------------------------------------------------------------------
                           (THOU)    (THOU)     (THOU)     (THOU)    (THOU)     (THOU)    (THOU)    (THOU)     (THOU)
 1  LOGGING                  0.        0.         0.         0.        0.         0.     14255.8       .0    14255.8
 2  SAWMILLS                 0.        0.         0.         0.        0.         0.     26514.2       .0    26514.2
 3  PLY&VENEER               0.        0.         0.         0.        0.         0.     43391.5    2337.7   45729.1
 4  FIBER PROD               0.        0.         0.         0.        0.         0.     32031.5    1725.7   33757.2
 5  FISHING                235.      105.       340.         0.        0.         0.      3974.9       .0     3974.9
 6  CROPS                  123.        0.       124.         0.        0.         0.      3272.3       .0     3272.3
 7  LIVESTOCK               33.        0.        33.         0.        0.         0.      4954.0       .0     4954.0
 8  MANUFACTUR            1376.        3.      1379.        74.        0.        74.     22805.8    1228.5   24034.3
 9  LODGING                 17.        0.        17.         0.        0.         0.      1632.5       .0     1632.5
10  EATERIES                 0.        0.         0.         0.        0.         0.      5681.8       .0     5681.8
11  SERV STA               168.        1.       168.         0.        0.         0.      8701.2       .0     8701.2
12  CAR DEALER             753.      207.       959.         0.        0.         0.     19799.3       .0    19799.3
13  COM,TRAN,U             956.        1.       957.         2.        0.         2.     39616.9      87.6   39704.5
14  PROF SERV              151.        0.       151.         0.        0.         0.      5552.1       .0     5552.1
15  FINANCIAL              298.        0.       299.         0.        0.         0.     11249.1       .0    11249.1
16  CONSTRUCT             4495.        1.      4496.         0.        0.         0.     31819.3       .0    31819.3
17  TRADE                 3014.        2.      3016.         0.        0.         0.     68675.1       .0    68675.1
18  RET SERV               282.        0.       282.         0.        0.         0.     12803.9       .0    12803.9
19  USFS SALES               0.        0.         0.         0.        0.         0.     18000.0       .0    18000.0
20  BLM SALES                0.        0.         0.         0.        0.         0.     18000.0       .0    18000.0
21  USFS APPRO               0.        0.         0.         0.        0.         0.          .0       .0         .0
22  BLM APPRO                0.        0.         0.         0.        0.         0.          .0       .0         .0
23  CNTY GOVT                0.        0.         0.         0.        0.         0.          .0       .0         .0
24  CITY GOVT                0.        0.         0.         0.        0.         0.          .0       .0         .0
25  ADMIN GOVT               0.        0.         0.         0.        0.         0.          .0       .0         .0
    TOTAL                11901.      322.     12222.        76.        0.        76.    392731.1    5379.5  398110.7
-----------------------------------------------------------------------------------------------------------------
```

Data table 3 verifies that the four wood products sectors did not invest during 1974.

Final year of simulation concludes

```
------------------------------------------------------------------------------------------------------------------
SUMMARY TABLE OF GENERAL ECONOMIC INDICATORS,
DOUGLAS CNTY, OREGON 1975-1975.
------------------------------------------------------------------------------------------------------------------
                                                                     EARNINGS                 LABOR      TOTAL
            POPU    EMPLOY      UN       GROSS                         PER        LOCAL        FORCE      LABOR
YEAR        LATION   MENT     EMPLOYED   OUTPUT    EXPORT     PCE     PERSON     DEMAND        RATE       FORCE
------------------------------------------------------------------------------------------------------------------
            (THOU)   (THOU)    (THOU)    (MILL)    (MILL)    (MILL)    (NO.)     (MILL)        (PCT)     (THOU)
1975          82.     24.8       7.7      694.     309.1     179.2     1916.      217.2        54.674     32.567
PCT           .6      -2.3      18.6      -2.0      -1.4        .7      -3.1       -2.4           .6        2.0
PCTB        1.76     -2.99     51.37     -1.29       .01      -.63     -5.53       -.20         1.13       6.05
APCB         .58     -1.01     14.82      -.43       .00      -.21     -1.88       -.07          .38       1.98
------------------------------------------------------------------------------------------------------------------
PCT ...PERCENTAGE CHANGE RELATIVE TO PREVIOUS YEAR
PCTB ...PERCENTAGE CHANGE RELATIVE TO BASE YEAR
APCB ...ANNUAL PERCENTAGE CHANGE RELATIVE TO BASE YEAR
```

The final year of simulation (1975) has been completed. Note that the final summary table includes two additional percentage changes: percentage change relative to base year and annual percentage change relative to the base year.

We will look at data table 1 again to trace the impact of the changes of investment on the Douglas County economy. Data table 3 verifies that the four wood products sectors did not invest in 1975.

```
(22) YEAR  1975 HAS BEEN REACHED
     DO YOU WANT TO SEE THE NEW DATA TABLES?
     [YES OR NO]
    ? yes
     Y

(23) WHAT TABLES DO YOU WANT TO SEE?
     TYPE NUMBERS [1-8]
    ? 1,3
     1,3
```

TABLE 1. EXPORT MARKET INDICATORS OF SPECIFIED SECTORS,
DOUGLAS CNTY, OREGON, 1975.

SECTOR		GROSS OUTPUT		ACTUAL MARKET SHARE			POTENTIAL MARKET SHARE	
NO.	TITLE	UNITED STATES	TOTAL REGION	REGIONAL EXPORT	PERCENT OF U.S. GROSS OUTPUT	ANNUAL CHANGE	EXPORTS	PERCENT OF U.S. GROSS OUTPUT
		(THOU)	(THOU)	(THOU)	(PERCENT)	(PERCENT)	(THOU)	(PERCENT)
1	LOGGING	3902693.	33822.	13948.	.3574	-37.1996	22232.	.5697
2	SAWMILLS	4746298.	38157.	35961.	.7577	-16.6337	43100.	.9081
3	PLY&VENEER	2682733.	117818.	113269.	4.2222	-30.0105	162845.	6.0701
4	FIBER PROD	29110355.	36034.	36217.	.1244	-22.4840	46722.	.1605
5	FISHING	5327455.	4749.	291.	.0055	-3.1812	301.	.0056
6	CROPS	35275682.	3942.	3604.	.0102	-3.9738	3753.	.0106
7	LIVESTOCK	38406312.	5838.	4538.	.0118	-.1622	4546.	.0118
8	MANUFACTUR	456928932.	54406.	47710.	.0104	.2854	47778.	.0105
9	LODGING	8774564.	4148.	2236.	.0255	-2.1575	2294.	.0261
10	EATERIES	46631163.	9974.	1485.	.0032	.0000	1485.	.0032
11	SERV STA	7192582.	21892.	5717.	.0795	-1.8329	5823.	.0810
12	CAR DEALER	16817125.	48255.	4633.	.0275	.1015	4633.	.0275
13	COM,TRAN,U	178216042.	28173.	3161.	.0018	.4147	3190.	.0018
14	PROF SERV	92083331.	14625.	2451.	.0027	-1.8423	3291.	.0036
15	FINANCIAL	35179522.	26503.	3160.	.0090	-2.5021	3277.	.0093
16	CONSTRUCT	153682974.	28320.	1845.	.0012	8.0060	1845.	.0012
17	TRADE	166220754.	96348.	10236.	.0062	9.5128	10290.	.0062
18	RET SERV	222794968.	32569.	9097.	.0041	-2.2929	9359.	.0042
19	USFS SALES	10000.	15287.	5787.	57.8727	-5.7335	6139.	61.3927
20	BLM SALES	10000.	14622.	1281.	12.8091	-32.0077	1884.	18.8390
21	USFS APPRO	0.	9859.	0.	.0000	.0000	0.	.0000
22	BLM APPRO	0.	1743.	0.	.0000	.0000	0.	.0000
23	CNTY GOVT	2000.	32250.	1782.	89.0871	.0000	1782.	89.0871
24	CITY GOVT	1000.	4324.	665.	66.5073	.0000	665.	66.5073
25	ADMIN GOVT	100000.	10343.	0.	.0000	.0000	0.	.0000
	TOTAL	1504096484.	694002.	309075.	.0000	.0000	387234.	.0000

TABLE 3. INVESTMENT AND CAPITAL STOCK INDICATORS OF SPECIFIED SECTORS,
DOUGLAS CNTY, OREGON, 1975.

SECTOR		PRODUCTION			POLLUTION ABATEMENT			CAPITAL STOCK		
NO.	NAME	EXPANSION	REPLACE MENT	TOTAL	EXPANSION	REPLACE MENT	TOTAL	PRODUCTION	POLLUTION ABATEMENT	TOTAL
		(THOU)	(THOU)	(THOU)	(THOU)	(THOU)	(THOU)	(THOU)	(THOU)	(THOU)
1	LOGGING	0.	0.	0.	0.	0.	0.	13414.1	.0	13414.1
2	SAWMILLS	0.	0.	0.	0.	0.	0.	25111.2	.0	25111.2
3	PLY&VENEER	0.	0.	0.	0.	0.	0.	41215.9	2220.4	43436.3
4	FIBER PROD	0.	0.	0.	0.	0.	0.	30486.7	1642.5	32129.2
5	FISHING	150.	113.	263.	0.	0.	0.	4124.9	.0	4124.9
6	CROPS	140.	0.	140.	0.	0.	0.	3411.9	.0	3411.9
7	LIVESTOCK	106.	0.	107.	0.	0.	0.	5060.2	.0	5060.2
8	MANUFACTUR	884.	3.	887.	48.	0.	48.	23689.9	1276.1	24966.1
9	LODGING	16.	0.	16.	0.	0.	0.	1648.7	.0	1648.7
10	EATERIES	0.	0.	0.	0.	0.	0.	5681.8	.0	5681.8
11	SERV STA	109.	1.	109.	0.	0.	0.	8809.7	.0	8809.7
12	CAR DEALER	194.	212.	406.	0.	0.	0.	19993.4	.0	19993.5
13	COM,TRAN,U	173.	1.	175.	0.	0.	0.	39790.3	88.0	39878.3
14	PROF SERV	268.	0.	269.	0.	0.	0.	5820.4	.0	5820.4
15	FINANCIAL	169.	0.	169.	0.	0.	0.	11417.8	.0	11417.9
16	CONSTRUCT	0.	1.	1.	0.	0.	0.	31819.3	.0	31819.3
17	TRADE	503.	2.	505.	0.	0.	0.	69177.7	.0	69177.7
18	RET SERV	211.	0.	211.	0.	0.	0.	13014.4	.0	13014.4
19	USFS SALES	0.	0.	0.	0.	0.	0.	18000.0	.0	18000.0
20	BLM SALES	0.	0.	0.	0.	0.	0.	18000.0	.0	18000.0
21	USFS APPRO	0.	0.	0.	0.	0.	0.	.0	.0	.0
22	BLM APPRO	0.	0.	0.	0.	0.	0.	.0	.0	.0
23	CNTY GOVT	0.	0.	0.	0.	0.	0.	.0	.0	.0
24	CITY GOVT	0.	0.	0.	0.	0.	0.	.0	.0	.0
25	ADMIN GOVT	0.	0.	0.	0.	0.	0.	.0	.0	.0
	TOTAL	2923.	335.	3257.	48.	0.	48.	389688.5	5227.1	394915.6

Saving projections for later analysis

Because there is no investment to replace depreciation, the value of capital stock for the wood products sectors, as expected, has noticeably declined during the years 1972 to 1975. Correspondingly, as the output capacity of these four sectors have declined, so has gross output (values excerpted from data tables 1 and 3):

	Capital Stock		**Gross Output**	
Sector	1972	1975	1972	1975
	($1000)		*($1000)*	
Logging	16,127.0	13,414.1	41,795	33,822
Sawmills	29,500.0	25,111.2	43,215	38,157
Plywood and veneer	48,094.0	41,215.9	137,520	117,818
Fiber products	35,360.0	30,486.7	41,794	36,034
Total	129,081.0	110,227.9	264,324	225,833

```
(24) SAVE 1975 DATA BASE FOR FUTURE USE?
    ? yes
     Y
```

Suppose we have a need to simulate 1975-78 at a later time. By responding "yes" to this question, we would not have to recreate the 1975 data base. The 1975 data base will be stored in the computer memory under whatever name we give in response to the following question:

```
(25) UNDER WHAT FILE NAME DO YOU WANT TO SAVE THE DATA?
    ? dc1975
     THE NEW DATA BASE HAS BEEN SAVED UNDER THE NAME
         DC1975
     PURGE IT WHEN YOU NO LONGER NEED IT BY TYPING
     PURGE,DC1975
```

Note: The name given the data file cannot begin with a number or be longer than seven characters.

For those who want more

```
(26) CONTINUE SIMULATION?
    ? no
     N
     IT HAS BEEN A PLEASURE TO WORK WITH YOU.
     HAVE A NICE DAY.
```

We answer "no" because we are finished. Had we answered "yes," IPASS would have "started over" using the projected 1975 Douglas County data base rather than the 1972 data.

Comparing Data From Analyses

We have made two, 3-year economic simulations using the 1972 Douglas County, Oregon, data base. The first analysis was a baseline analysis: IPASS derived all projections internally using only the data from the 1972 data base. For the second analysis we started with the 1972 data base, but asked, "What if the four wood products sectors in Douglas County chose not to invest?" The impact of this situation over the period 1973-75 can now be estimated by comparing the two analyses. The following tabulation compares gross regional output of the wood products sectors from the "baseline analysis" to that of the "no investment" analysis. All other factors in the two simulations remain equal; hence, any differences are attributable to the lack of investment (no expansion or maintenance of capital equipment) by the four wood products sectors.

Gross Regional Output

Year	Baseline analysis	"No investment" analysis	Difference
	- - - - *(Millions of dollars)* - - - -		
1972	703	703	-0
1973	740	713	-27
1974	775	708	-67
1975	793	694	-99
Totals	2,959	2,767	-193

The hypothetical lack of investment by the wood products sectors would cause an overall loss of $193 million of gross regional output over 3 years.

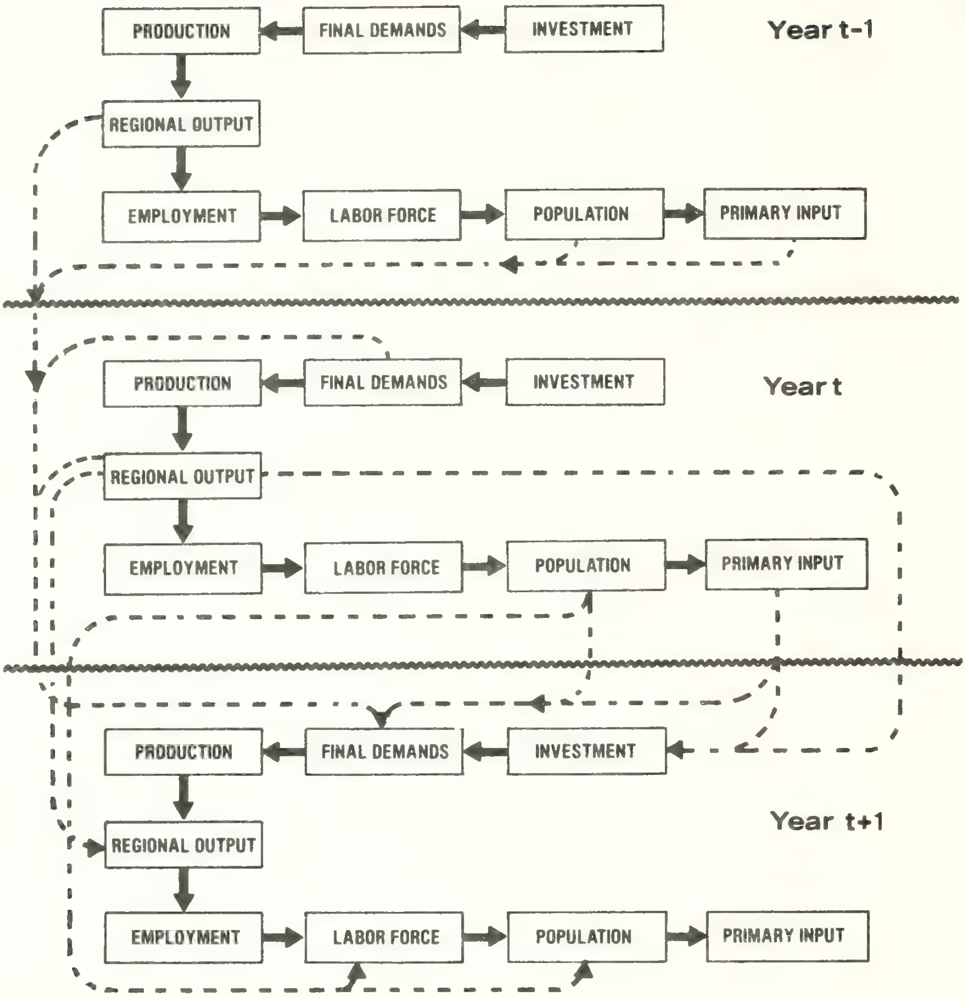
What would happen if the companies have a change of heart and begin investing again in 1975? How would the construction of a new pulpmill in 1974 affect the Douglas County economy? What would happen to the Douglas County economy in a national housing boom? What will the Douglas County economy look like in 1983? These kind of questions and many others are easily simulated using the IPASS model.

Basic IPASS Logic

To fully understand the usefulness of the IPASS model and, in particular, what impacts can be examined, the user must understand the fundamental logic. The computations (called algorithms) involved can be roughly separated into eight main groupings or "modules." These interrelated modules are investment, final demands, production, regional output, employment, labor force, population, and primary input (see fig. 2). Socioeconomic projections derived from a particular module are input used for subsequent calculations. This is a basic characteristic of the model's dynamic nature: next year's projections are based on this and previous years' output. Figure 4 shows the intertemporal relationships in the IPASS simulation model.

The following discussion describes the data (input) required and calculated estimates (output) associated with each module.

Figure 4.--IPASS is a dynamic, recursive system. Estimates for the current year t are influenced by transactions from previous years and preceding steps in the current year. For example, the level of investment for year t is a function of regional output and primary input for year t-1.



Investment Module

Algorithms composing the investment module determine the amount of investments needed to either replace depreciated capacity or to expand capacity. In addition, the investment module calculates accumulated business income and the extent of depreciated but not replaced capacity, or capital stocks.

The calculations of this module play an important role in determining the extent to which an economy can respond to increases in demand for its products. The standard (static) I/O model assumes a certain and instantaneous increase in the output of goods and services if final demand increases. But an economy's ability to increase output depends on available capacity. Prospective increases in demand may require more capacity than is currently available--that is, the impact of a change in final demand may require additional investment and, therefore, time. The extent to which an increase in final demand can be accomodated depends on the availability of investment funds to (1) maintain existing capacity, and, if necessary (2) expand existing capacity. The amount of investment funds available to maintain and/or add to capacity is a function of current and accumulated business income. Conceivably, output could decrease although final demands increase. If funds available are not sufficient to replace depreciated capital stocks, past output levels cannot be maintained.

Final Demands Module

Final demands are represented by the Y variable in the Leontief I/O model ($[X] = [I-A]^{-1} [Y]$). The user of an ordinary I/O model "externally" specifies changes in final demand and observes the impact on an economy's gross output. IPASS will allow the same kinds of nonprogramed changes and, in addition, has the ability to generate changes in final demand internally. For example, the investment module triggers changes in the "gross private capital formation" (GPCF) component of final demand. Likewise, personal consumption expenditures (PCE) are internally motivated by population changes. Eventually, a government module, not yet available, will provide for changes in government--Federal, State and local services.

The seven components of final demand and how they relate to one another are as follows:

1. **Gross private capital formation** (GPCF) represents purchases of locally produced capital stock items resulting from new investment. GPCF provides new equipment or facilities for use in the production process. The data base for each study area contains a unique investment matrix. The investment matrix translates the investment by sector into purchases from capital stock producing sectors for GPCF. Total GPCF will rarely equal total investment, particularly for small areas, since a significant portion of investment will be spent on imported capital goods.

2. **Personal consumption expenditures** (PCE) are purchases by household members of products for personal consumption. PCE will increase as population and total disposable income per worker increases. An income elasticity of demand, which is sector-specific, applies to increases (or decreases) in total disposable income. Consequently, income growth will cause a different change in PCE for different sectors.

3. **Change in business inventory,** if positive, represents an accumulation of inventory items; a negative change signifies a depletion of inventory. The change in business inventory for the current year is determined by multiplying an inventory accumulation rate by the difference in area output for the 2 previous years.

4 and 5. **State government expenditures and federal government expenditures** are local expenditures. In its present form, IPASS assumes that government expenditures are proportional to local population. Thus, an increase (or decrease) in population will cause a proportional increase (or decrease) in government expenditures. Negative government expenditures will occur when sale of government surplus exceeds government purchases of goods for a given sector.

6. **Exports** are goods and services purchased from local producers by nonlocal users. The amount of exports is dependent on U.S. gross output and the region's market share of the nation's output of goods and services. IPASS will accomodate various assumptions regarding regional market share. A constant share would mean that as the U.S. economy grew, regional growth would follow proportionately, all other things being equal. On the other hand, an increasing market share would mean the demand for area goods and services will grow at a faster rate than the U.S. economy. Of course, it works both ways: the regional market share and/or the U.S. gross output may decrease, precipitating a decrease in regional exports.

7. **User-specified final demand** allows the user to introduce changes in final demand by sector. The other final demands are determined internally by IPASS computations, but only the user can change the user-specified final demands (see example 2, question 16). This special component will help the user avoid analytical errors because change in final demand is uniquely identified. To monitor the potential impact of any change in user-specified final demand, the user should answer “yes” to the IPASS question, “WOULD YOU LIKE TO VIEW THE CHANGE IN GROSS OUTPUT RESULTING FROM USER-SPECIFIED FINAL DEMANDS’?

Production Module

The production module is a Leontief inverse $[I-A]^{-1}$ for the local area being analyzed. Summing all final demands from the final demands module and performing the conventional Leontief calculation yields the regional output required to meet all intermediate (internal) and external demands. This “regional output demanded” is not the actual output for the region, but rather the maximum potential output for all goods and services. There may be constraints on producers that do not allow them to meet these demands. Actual regional output is estimated by the regional output module.

Regional Output Module

The main purpose of the regional output module is to predict the actual regional output for each sector based on regional output demanded and the regional output constraints; i.e., capital stock and/or employment.

Capital stock is adjusted upward by the amount of expansion investment or downward by the amount of depreciation that was not replaced. Output capacity is then determined by multiplying total capital stock by a output/capital stock ratio. If output capacity exceeds output demanded, then there is no binding constraint. Alternately, if demand exceeds capacity, then not all demands can be met. In such instances, IPASS assumes that all intermediate (interindustry) and local final demands are met before products and services are exported to users outside the local areas.

If the available labor force, by occupation, is insufficient to meet demands, then exports must be further reduced to reflect the constraint on output capacity.

Employment Module

Employee productivity parameters (for example, output per hour and hours worked per year) are updated.

Employment by sector is a function of sector output and output per worker. The output-per-worker ratio is affected by several factors: output per hour, hours worked per week, and weeks worked per year.

Unemployment exists when labor supply exceeds demand after accounting for all migration and commuting.

Labor Force Module

Demand for labor by occupation as well as the area’s supply of labor is calculated by the labor force module.

The occupational matrix converts employment by sector to labor force demanded by occupation.

The available labor force represents the product of labor force participation rates by sex and age and the resident population. This labor force is then classified into the various occupations by labor force/occupation ratios.

When labor supply exceeds demand for an occupation, part of the excess supply will commute to a job outside the area and part will migrate away. Conversely, when demand exceeds supply for a particular occupation, more workers will commute from residences outside of the area and some may migrate into the area.

If a labor output constraint is introduced (that is, if labor supplied is less than labor demanded), the employment module will allocate the available labor and will adjust regional output downward.

Population Module

Population is affected by migration of labor and cohort movements such as the movement of college students and retirees. The population module also determines births and mortality, and ages the population 1 year for each year of simulation.

Primary Input Module

Value added, indirect business taxes and imports are determined by the primary input module. Direct coefficients, such as those shown in table 2, are multiplied by estimated regional outputs.

Earnings by sector are the products of earnings per worker and total sector employment. Earnings are subtracted from value added to determine business income. Indirect and income taxes are subtracted from business income to obtain net business income. Total personal income is the sum of earnings by wage earners, proprietor income, transfer payments, and unemployment compensation.

Finally, depreciation/output ratios are used to calculate actual depreciation. Actual depreciation tends to be less than the "book value" depreciation reported by industries.

Literature Cited

Darr, David R.; Fight, Roger D. Douglas County, Oregon: potential economic impacts of a changing timber resource base. Res. Pap. PNW-179. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1974.** 41 p.

Appendix A: How to Obtain IPASS Socioeconomic Data

There are four ways the user can view the analytical results of IPASS: data tables, annual summary tables, parameters, and optional outputs.

Data Tables

Values of socioeconomic indicators for the current year of simulation are displayed in eight data tables. Each indicator is broken down by sector, occupation, or age class. The user has the opportunity to view data tables when IPASS asks:

```
DO YOU WANT TO SEE THE (year) DATA TABLES?
[YES OR NO]
```

If the user responds "yes," IPASS will then ask:

```
WHAT TABLES DO YOU WANT TO SEE?
TYPE NUMBERS [1-8]
```

The user can then key in the number(s) corresponding to the table(s) desired. The choices are:

1 = Export market indicators. Compares a region's actual and potential market share of the U.S. gross outputs by sector.

2 = Intermediate and final demand indicators. Describes five final demand components (all components except exports, which are given in data table 1) plus sales to local industries (intermediate sales) by sector.

3 = Investment and capital stock indicators. Describes current investment levels in production and pollution abatement by sector. Also provides estimates of capital stock

4 = Intermediate purchases, imports, and value added indicators. Describes imports, earnings (wages paid to employees), other value added (taxes paid and business income), and intermediate purchases by sector.

5 = Output, earnings, and employee compensation per worker. Describes by sector.

6 = Employment and unemployment. Describes by sector and occupation.

7 = Total population and labor force indicators. Describes population, labor force, and labor force participation rates by sex and by age class.

8 = Productivity indicators. Describes employment, arverage hours worked per week and per year, weeks worked per year, and output produced by all workers, by sector.

An example of each of these tables follows.

TABLE 1. EXPORT MARKET INDICATORS OF SPECIFIED SECTORS,
DOUGLAS CNTY, OREGON, 1972.

SECTOR		GROSS OUTPUT		ACTUAL MARKET SHARE			POTENTIAL MARKET SHARE	
NO.	TITLE	UNITED STATES	TOTAL REGION	REGIONAL EXPORT	PERCENT OF U.S. GROSS OUTPUT	ANNUAL CHANGE	EXPORTS	PERCENT OF U.S. GROSS OUTPUT
		(THOU)	(THOU)	(THOU)	(PERCENT)	(PERCENT)	(THOU)	(PERCENT)
1	LOGGING	3447545.	41796.	18934.	.5492	.0000	19582.	.5680
2	SAWMILLS	4493815.	43196.	40908.	.9103	.0000	40907.	.9103
3	PLY&VENEER	2329338.	137520.	131601.	5.6497	.0000	138784.	5.9581
4	FIBER PROD	26360411.	41794.	41896.	.1589	.0000	42177.	.1600
5	FISHING	4777643.	4210.	243.	.0051	.0000	268.	.0056
6	CROPS	31339156.	3505.	3214.	.0103	.0000	3322.	.0106
7	LIVESTOCK	36537238.	5464.	4311.	.0118	.0000	4311.	.0118
8	MANUFACTUR	413504121.	48412.	42084.	.0102	.0000	42591.	.0103
9	LODGING	8290052.	3826.	1924.	.0232	.0000	2147.	.0259
10	EATERIES	43882706.	9279.	732.	.0017	.0000	1404.	.0032
11	SERV STA	6295169.	20106.	4065.	.0646	.0000	5099.	.0810
12	CAR DEALER	14688960.	44697.	1674.	.0114	.0000	4039.	.0275
13	COM,TRAN,U	159188514.	25543.	613.	.0004	.0000	2706.	.0017
14	PROF SERV	84429033.	11834.	-252.	-.0003	.0000	1351.	.0016
15	FINANCIAL	31574623.	26270.	2236.	.0071	.0000	2842.	.0090
16	CONSTRUCT	146778672.	26580.	-1061.	-.0007	.0000	1321.	.0009
17	TRADE	149693686.	85942.	854.	.0006	.0000	6886.	.0046
18	RET SERV	197744310.	29327.	6573.	.0033	.0000	8108.	.0041
19	USFS SALES	10000.	17180.	6139.	61.3927	.0000	6139.	61.3927
20	BLM SALES	10000.	17464.	1874.	18.7412	.0000	1884.	18.8390
21	USFS APPRO	0.	9595.	0.	.0000	.0000	0.	.0000
22	BLM APPRO	0.	1696.	0.	.0000	.0000	0.	.0000
23	CNTY GOVT	2000.	33015.	1782.	89.0871	.0000	1782.	89.0871
24	CITY GOVT	1000.	4253.	665.	66.5073	.0000	665.	66.5073
25	ADMIN GOVT	100000.	10194.	0.	.0000	.0000	0.	.0000
	TOTAL	1365477992.	702697.	311010.	.0000	.0000	338315.	.0000

TABLE 2. INTERMEDIATE AND FINAL DEMAND INDICATORS OF SPECIFIED SECTORS,
DOUGLAS CNTY, OREGON, 1972.

SECTOR			FINAL LOCAL DEMAND					
						GOVERNMENT		
NO.	NAME	INTERMEDIATE SALES	PERSONAL CONSUMPTION EXPENDITURES	GROSS PRIVATE CAPITAL FORMATION	INVENTORY CHANGE	STATE AND LOCAL	FEDERAL	TOTAL
		(THOU)	(THOU)	(THOU)	(THOU)	(THOU)	(THOU)	(THOU)
1	LOGGING	22837.	35.	0.	-233.	83.	139.	24.
2	SAWMILLS	2100.	265.	0.	-353.	103.	174.	189.
3	PLY&VENEER	5303.	714.	0.	-104.	2.	4.	616.
4	FIBER PROD	4.	0.	0.	-107.	0.	0.	-107.
5	FISHING	3937.	31.	0.	-2.	0.	0.	29.
6	CROPS	79.	144.	0.	29.	15.	25.	212.
7	LIVESTOCK	1045.	144.	0.	-37.	0.	0.	108.
8	MANUFACTUR	4928.	798.	674.	-176.	38.	64.	1399.
9	LODGING	60.	1558.	0.	-13.	111.	186.	1842.
10	EATERIES	51.	8527.	0.	-46.	6.	9.	8495.
11	SERV STA	3876.	12060.	0.	-5.	41.	69.	12165.
12	CAR DEALER	9971.	32316.	0.	-220.	357.	599.	33053.
13	COM,TRAN,U	10151.	10936.	143.	10.	1378.	2312.	14778.
14	PROF SERV	1383.	9939.	0.	-1.	285.	479.	10703.
15	FINANCIAL	16451.	6844.	0.	-1.	277.	464.	7584.
16	CONSTRUCT	14851.	6250.	2267.	-21.	1604.	2690.	12789.
17	TRADE	20336.	64165.	766.	-1198.	380.	638.	64752.
18	RET SERV	7108.	14303.	0.	-36.	515.	863.	15645.
19	USFS SALES	10990.	51.	0.	0.	0.	0.	51.
20	BLM SALES	15578.	12.	0.	0.	0.	0.	12.
21	USFS APPRO	0.	0.	0.	0.	0.	9595.	9595.
22	BLM APPRO	0.	0.	0.	0.	0.	1696.	1696.
23	CNTY GOVT	13299.	7894.	0.	0.	3750.	6290.	17934.
24	CITY GOVT	1693.	1737.	0.	0.	59.	99.	1895.
25	ADMIN GOVT	0.	0.	0.	0.	0.	0.	0.
	TOTAL	166032.	178724.	3852.	-2514.	9005.	26394.	215461.

TABLE 3. INVESTMENT AND CAPITAL STOCK INDICATORS OF SPECIFIED SECTORS, DOUGLAS CNTY, OREGON, 1972.

SECTOR		PRODUCTION			POLLUTION ABATEMENT			CAPITAL STOCK		
NO.	NAME	EXPANSION	REPLACE MENT	TOTAL	EXPANSION	REPLACE MENT	TOTAL	PRODUCTION	POLLUTION ABATEMENT	TOTAL
		(THOU)	(THOU)	(THOU)	(THOU)	(THOU)	(THOU)	(THOU)	(THOU)	(THOU)
1	LOGGING	0.	879.	879.	0.	0.	0.	16127.0	.0	16127.0
2	SAWMILLS	0.	1387.	1387.	0.	0.	0.	29500.0	.0	29500.0
3	PLY&VENEER	102.	2277.	2379.	5.	123.	128.	48094.0	2590.0	50684.0
4	FIBER PROD	0.	1580.	1580.	0.	85.	85.	35360.0	1905.0	37265.0
5	FISHING	0.	93.	93.	0.	0.	0.	3665.0	.0	3665.0
6	CROPS	0.	0.	0.	0.	0.	0.	3034.0	.0	3034.0
7	LIVESTOCK	0.	0.	0.	0.	0.	0.	4921.0	.0	4921.0
8	MANUFACTUR	0.	3.	3.	0.	0.	0.	21014.0	1132.0	22146.0
9	LODGING	0.	0.	0.	0.	0.	0.	1521.0	.0	1521.0
10	EATERIES	0.	0.	0.	0.	0.	0.	5261.0	.0	5261.0
11	SERV STA	0.	1.	1.	0.	0.	0.	8002.0	.0	8002.0
12	CAR DEALER	0.	183.	183.	0.	0.	0.	17793.0	.0	17793.0
13	COM,TRAN,U	1839.	1.	1840.	4.	0.	4.	34865.0	77.0	34942.0
14	PROF SERV	67.	0.	67.	0.	0.	0.	4707.0	.0	4707.0
15	FINANCIAL	0.	0.	0.	0.	0.	0.	10490.0	.0	10490.0
16	CONSTRUCT	832.	1.	833.	0.	0.	0.	24305.0	.0	24305.0
17	TRADE	0.	2.	2.	0.	0.	0.	60340.0	.0	60340.0
18	RET SERV	0.	0.	0.	0.	0.	0.	11682.0	.0	11682.0
19	USFS SALES	0.	0.	0.	0.	0.	0.	18000.0	.0	18000.0
20	BLM SALES	0.	0.	0.	0.	0.	0.	18000.0	.0	18000.0
21	USFS APPRO	0.	0.	0.	0.	0.	0.	.0	.0	.0
22	BLM APPRO	0.	0.	0.	0.	0.	0.	.0	.0	.0
23	CNTY GOVT	0.	0.	0.	0.	0.	0.	.0	.0	.0
24	CITY GOVT	0.	0.	0.	0.	0.	0.	.0	.0	.0
25	ADMIN GOVT	0.	0.	0.	0.	0.	0.	.0	.0	.0
	TOTAL	2840.	6407.	9247.	9.	208.	217.	376681.0	5704.0	382385.0

TABLE 4. INTERMEDIATE PURCHASES, IMPORTS, AND VALUE ADDED INDICATORS OF SPECIFIED SECTORS, DOUGLAS CNTY, OREGON, 1972.

SECTOR		INTERMEDIATE PURCHASES	VALUE ADDED			IMPORTS
NO.	NAME		EARNINGS	OTHER	TOTAL	
		(THOU)	(THOU)	(THOU)	(THOU)	(THOU)
1	LOGGING	16694.	11921.	3986.	15907.	9194.
2	SAWMILLS	30161.	9456.	3567.	13023.	13.
3	PLY&VENEER	38475.	38134.	10120.	48254.	50791.
4	FIBER PROD	3899.	4495.	982.	5477.	32418.
5	FISHING	1432.	1645.	200.	1645.	933.
6	CROPS	3046.	235.	130.	365.	94.
7	LIVESTOCK	3993.	708.	605.	1313.	158.
8	MANUFACTUR	7592.	8220.	3474.	11694.	29125.
9	LODGING	3001.	509.	296.	805.	21.
10	EATERIES	2940.	2696.	840.	3536.	2803.
11	SERV STA	2380.	2498.	412.	2910.	14816.
12	CAR DEALER	2836.	5056.	793.	5849.	36013.
13	COM,TRAN,U	2333.	7106.	4196.	11302.	11909.
14	PROF SERV	1896.	6196.	1610.	7806.	2132.
15	FINANCIAL	1525.	2641.	766.	3407.	21337.
16	CONSTRUCT	7873.	5750.	1673.	7423.	11283.
17	TRADE	12011.	12974.	3375.	16349.	57582.
18	RET SERV	2084.	7349.	1259.	8608.	18635.
19	USFS SALES	5404.	0.	10489.	10489.	1288.
20	BLM SALES	5053.	0.	11991.	11991.	420.
21	USFS APPRO	2485.	4844.	0.	4844.	2266.
22	BLM APPRO	118.	1261.	1.	1262.	317.
23	CNTY GOVT	7646.	18614.	1676.	20290.	5079.
24	CITY GOVT	937.	1029.	401.	1430.	1886.
25	ADMIN GOVT	0.	10194.	0.	10194.	0.
	TOTAL	165811.	163531.	62842.	226373.	310513.

TABLE 5. OUTPUT, EARNINGS, AND EMPLOYEE COMPENSATION PER WORKER FOR SPECIFIED SECTORS, DOUGLAS CNTY, OREGON, 1972.

SECTOR		OUTPUT PER WORKER		EARNINGS PER WORKER		EMPLOYEE COMPENSATION PER WORKER	
NO.	NAME	TOTAL	ANNUAL CHANGE	TOTAL	ANNUAL CHANGE	TOTAL	ANNUAL CHANGE
		(DOLLAR)	(PCT)	(DOLLAR)	(PCT)	(DOLLAR)	(PCT)
1	LOGGING	14240.	.0	4062.	.0	4062.	.0
2	SAWMILLS	22916.	.0	5016.	.0	5016.	.0
3	PLY&VENEER	39013.	.0	10818.	.0	10818.	.0
4	FIBER PROD	70479.	.0	7580.	.0	7580.	.0
5	FISHING	15886.	.0	6208.	.0	6208.	.0
6	CROPS	4971.	.0	333.	.0	333.	.0
7	LIVESTOCK	13558.	.0	1757.	.0	1757.	.0
8	MANUFACTUR	30640.	.0	5203.	.0	5203.	.0
9	LODGING	8038.	.0	1069.	.0	1069.	.0
10	EATERIES	8218.	.0	2388.	.0	2388.	.0
11	SERV STA	47087.	.0	5850.	.0	5850.	.0
12	CAR DEALER	78831.	.0	8917.	.0	8917.	.0
13	COM,TRAN,U	25265.	.0	7029.	.0	7029.	.0
14	PROF SERV	14556.	.0	7621.	.0	7621.	.0
15	FINANCIAL	84741.	.0	8519.	.0	8519.	.0
16	CONSTRUCT	25387.	.0	5492.	.0	5492.	.0
17	TRADE	45763.	.0	6908.	.0	6908.	.0
18	RET SERV	28837.	.0	7226.	.0	7226.	.0
19	USFS SALES	0.	.0	0.	.0	0.	.0
20	BLM SALES	0.	.0	0.	.0	0.	.0
21	USFS APPRO	20904.	.0	10553.	.0	10553.	.0
22	BLM APPRO	12117.	.0	9007.	.0	9007.	.0
23	CNTY GOVT	10667.	.0	6014.	.0	6014.	.0
24	CITY GOVT	24872.	.0	6018.	.0	6018.	.0
25	ADMIN GOVT	8982.	.0	8981.	.0	8981.	.0
	AVERAGE	26131.	.0	6396.	.0	6396.	.0

TABLE 6. EMPLOYMENT AND UNEMPLOYMENT IN SPECIFIED SECTORS, BY OCCUPATION, DOUGLAS CNTY, OREGON, 1972.

SECTOR											
NO.	NAME	PROFES SIONAL	MANA-GERIAL	SALES WORKER	CLER-ICAL	CRAFTS	OPERA-TIVES	NOFARM NOMINE	SER-VICE	FARM	TOTAL
		(NO.)	(NO.)	(NO.)	(NO.)	(NO.)	(NO.)	(NO.)	(NO.)	(NO.)	(NO.)
1	LOGGING	56.	106.	1.	61.	920.	487.	39.	1264.	0.	2935.
2	SAWMILLS	48.	56.	8.	88.	400.	579.	75.	631.	0.	1885.
3	PLY&VENEER	100.	122.	24.	178.	647.	1442.	106.	906.	0.	3525.
4	FIBER PROD	56.	19.	0.	47.	208.	168.	15.	80.	0.	593.
5	FISHING	23.	44.	0.	7.	4.	15.	14.	158.	0.	265.
6	CROPS	0.	52.	0.	0.	80.	0.	0.	0.	572.	705.
7	LIVESTOCK	0.	30.	0.	0.	46.	0.	0.	0.	327.	403.
8	MANUFACTUR	81.	100.	63.	157.	451.	532.	17.	179.	0.	1580.
9	LODGING	2.	45.	2.	53.	12.	12.	349.	2.	0.	476.
10	EATERIES	5.	45.	3.	27.	7.	2.	1039.	0.	0.	1129.
11	SERV STA	3.	55.	70.	43.	104.	127.	4.	19.	0.	427.
12	CAR DEALER	5.	73.	93.	58.	138.	169.	6.	26.	0.	567.
13	COM,TRAN,U	73.	93.	18.	234.	177.	340.	10.	66.	0.	1011.
14	PROF SERV	272.	40.	1.	182.	16.	8.	293.	1.	0.	813.
15	FINANCIAL	3.	66.	69.	159.	4.	0.	8.	2.	0.	310.
16	CONSTRUCT	6.	126.	10.	86.	562.	96.	9.	153.	0.	1047.
17	TRADE	17.	154.	333.	284.	120.	177.	706.	86.	0.	1878.
18	RET SERV	118.	92.	30.	153.	105.	77.	381.	62.	0.	1017.
19	USFS SALES	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20	BLM SALES	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
21	USFS APPRO	190.	31.	0.	165.	31.	7.	23.	13.	0.	459.
22	BLM APPRO	58.	9.	0.	50.	9.	2.	7.	4.	0.	140.
23	CNTY GOVT	1279.	199.	5.	616.	171.	116.	580.	125.	4.	3095.
24	CITY GOVT	71.	11.	0.	34.	9.	6.	32.	7.	0.	171.
25	ADMIN GOVT	458.	99.	2.	373.	67.	21.	76.	39.	0.	1135.
	TOTAL	2924.	1669.	734.	3055.	4290.	4382.	3790.	3819.	904.	25566.
UNEMPLOYMENT		418.	534.	733.	402.	267.	1220.	145.	280.	93.	4092.

```
-------------------------------------------------------------------------------------------------
TABLE 7.  TOTAL POPULATION AND LABOR FORCE INDICATORS OF SPECIFIED AGE CLASS,
          DOUGLAS CNTY, OREGON, 1972.
-------------------------------------------------------------------------------------------------
AGE GROUP                  POPULATION                LABOR FORCE          PARTICIPATION RATE
----------           --------------------       --------------------     --------------------
NO.  YEARS            MALE        FEMALE         MALE        FEMALE       MALE        FEMALE
-------------------------------------------------------------------------------------------------
                      (NO.)       (NO.)          (NO.)       (NO.)        (PCT)       (PCT)
 1    1- 4            2363.       2261.
 2    5- 9            3327.       3272.
 3   10-11            1788.       1624.
 4   12-13            1770.       1737.
 5   14-15            1767.       1694.
 6   16-17            1842.       1745.           558.        347.        30.27       19.89
 7   18-19            1786.       1671.          1219.        663.        68.27       39.68
 8   20-24            2624.       2926.          2330.       1202.        88.81       41.06
 9   25-29            2246.       2583.          2140.        996.        95.26       38.57
10   30-34            2323.       2478.          2213.        956.        95.26       38.57
11   35-44            4489.       4597.          4127.       2190.        91.94       47.65
12   45-54            4641.       4570.          3811.       1881.        82.12       41.16
13   55-59            2160.       2069.          1749.        843.        80.98       40.73
14   60-64            1893.       1827.          1488.        727.        78.62       39.79
15   65+               344.        330.            69.         29.        19.94        8.93
    TOTAL            35363.      35384.         19705.       9834.        55.72       27.79
-------------------------------------------------------------------------------------------------
```

```
-----------------------------------------------------------------------------------------------------
TABLE 8.  PRODUCTIVITY INDICATORS OF SPECIFIED SECTORS,
          DOUGLAS CNTY, OREGON, 1972.
-----------------------------------------------------------------------------------------------------
                                                           TOTAL HOURS       OUTPUT
                                                            PER YEAR       PER WORKER
     SECTOR                                              ---------------  ------------
----------                  HOURS WORKED  WEEKS WORKED     PER     ALL     PER    PER
NO.   NAME      EMPLOYMENT    PER WEEK      PER YEAR     WORKER  WORKERS   HOUR   YEAR   TOTAL OUTPUT
-----------------------------------------------------------------------------------------------------
                  (NO.)        (NO.)         (NO.)       (NO.)   (THOU)   (NO.)  (NO.)     (THOU)
 1 LOGGING        2935.        23.05         52.00       1198.7  3518.2   11.88  14240.     41796.
 2 SAWMILLS       1885.        44.48         52.00       2313.2  4360.3    9.91  22916.     43196.
 3 PLY&VENEER     3525.        39.74         52.00       2066.6  7284.9   18.88  39013.    137520.
 4 FIBER PROD      593.        40.70         52.00       2116.5  1255.1   33.30  70479.     41794.
 5 FISHING         265.        44.36         52.00       2307.0   611.3    6.90  15886.      4210.
 6 CROPS           705.        25.66         52.00       1334.3   940.7    3.73   4971.      3505.
 7 LIVESTOCK       403.        22.78         52.00       1184.4   477.3   11.44  13558.      5464.
 8 MANUFACTUR     1580.        34.34         52.00       1785.9  2821.7   17.16  30640.     48412.
 9 LODGING         476.        41.00         52.00       2132.2  1014.9    3.77   8038.      3826.
10 EATERIES       1129.        18.77         52.00        976.3  1102.2    8.42   8218.      9279.
11 SERV STA        427.        39.80         52.00       2069.6   883.7   22.73  47087.     20106.
12 CAR DEALER      567.        39.52         52.00       2055.1  1165.2   38.36  78831.     44697.
13 COM,TRAN,U     1011.        35.60         52.00       1851.0  1871.4   13.65  25265.     25543.
14 PROF SERV       813.        41.16         52.00       2140.4  1740.2    6.80  14556.     11834.
15 FINANCIAL       310.        36.73         52.00       1909.9   592.1   44.36  84741.     26270.
16 CONSTRUCT      1047.        37.99         52.00       1975.3  2068.1   12.85  25387.     26580.
17 TRADE          1878.        35.67         52.00       1854.7  3483.1   24.68  45763.     85942.
18 RET SERV       1017.        40.67         52.00       2114.7  2150.7   13.64  28837.     29327.
19 USFS SALES        0.          .00         52.00           .0      .0     .00      0.     17180.
20 BLM SALES         0.          .00         52.00           .0      .0     .00      0.     17464.
21 USFS APPRO      459.        40.00         52.00       2080.0   954.7   10.06  20904.      9595.
22 BLM APPRO       140.        40.00         52.00       2080.0   291.2    5.84  12117.      1696.
23 CNTY GOVT      3095.        40.00         52.00       2080.0  6437.6    5.13  10667.     33015.
24 CITY GOVT       171.        40.00         52.00       2080.0   355.7   11.95  24872.      4253.
25 ADMIN GOVT     1135.        40.00         52.00       2080.0  2360.8    4.32   8982.     10194.
-----------------------------------------------------------------------------------------------------
```

Annual Summary Tables

Annual summary tables provide indicator totals and annual percentage changes for each indicator. IPASS asks the user to select a table:

```
WHICH ANNUAL SUMMARY TABLE DO YOU WANT TO FOLLOW?
TYPE ONE NUMBER [0-6]
```

Although there are six different tables available, only one may be printed during each simulation. The user keys the number corresponding to the table desired:

0 = No table. When a summary is not needed for a particular analysis.

1 = Market indicators. Compares the region's actual, potential, and constrained outputs. Also gives U.S. gross outputs and the region's market share of that output.

2 = Final demand indicators. Displays totals for each component of final demand.

3 = Investment indicators. Displays totals for current replacement and expansion investment for production stock and pollution abatement equipment, as well as value of existing capital stock.

4 = Total employment by occupation. Displays totals for all sectors.

5 = Labor force indicators. Displays population totals by sex, number of in- and out-migrating workers, number of in- and out-commuting workers, and total labor force over 16 years old.

6 = Select economic indicators. Includes a broad spectrum of indicator totals--population, employment, unemployment, gross output, exports, personal consumption expenditures, average earnings per person, local final demands (all final demands excluding exports), and labor force rate (as a percentage of all persons over 16 years old).

Values in each table are annual values. A new table title is printed for each year of data if there is intervening output. An example of each table follows.

Annual summary table 1:

```
------------------------------------------------------------------------------------------------------
SUMMARY TABLE OF SELECTED MARKET INDICATORS,
DOUGLAS CNTY, OREGON 1973-1973.
------------------------------------------------------------------------------------------------------
                                       REGIONAL GROSS OUTPUT                         EXPORTS
                         ---------------------------------------------------  ------------------------
              U.S. GROSS                                       LABOR         U.S.
YEAR           OUTPUT       ACTUAL    POTENTIAL     CAPACITY   CONSTRAINT   ALLOCATION       REGION
------------------------------------------------------------------------------------------------------
                  (MILL)       (MILL)       (MILL)       (MILL)       (MILL)       (MILL)       (MILL)
1973               1410.         686.         755.         693.         686.         353.         301.
PCT                  3.3         -2.4          2.5         -2.0         -2.4          4.5         -3.3
PCTB                3.27        -2.36         2.53        -2.02        -2.36         4.48        -3.32
APCB                3.27        -2.36         2.53        -2.02        -2.36         4.48        -3.32
------------------------------------------------------------------------------------------------------
PCT ...PERCENTAGE CHANGE RELATIVE TO PREVIOUS YEAR
PCTB ...PERCENTAGE CHANGE RELATIVE TO BASE YEAR
APCB ...ANNUAL PERCENTAGE CHANGE RELATIVE TO BASE YEAR
```

Annual summary table 2:

```
--------------------------------------------------------------------------------------------------------------------
SUMMARY TABLE OF SELECTED FINAL DEMAND INDICATORS,
DOUGLAS CNTY, OREGON 1973-1973.
--------------------------------------------------------------------------------------------------------------------
             PERSONAL       GROSS PRIVATE  BUSINESS                              GOVERNMENT
             CONSUMPTION    CAPITAL        INVENTORY                    -----------------------------
YEAR         EXPENDITURE    FORMATION      CHANGE                EXPORTS STATE AND LOCAL       FEDERAL          TOTAL
--------------------------------------------------------------------------------------------------------------------
                    (THOU)         (THOU)         (THOU)         (THOU)         (THOU)         (THOU)         (THOU)
1973                  173.             0.             6.           301.             9.            26.           514.
PCT                   -3.4         -100.0             -I           -3.3           -1.3           -1.3           -2.3
PCTB                 -3.37        -100.00             -I          -3.32          -1.32          -1.32          -2.27
APCB                 -3.37            .00             -I          -3.32          -1.32          -1.32          -2.27
--------------------------------------------------------------------------------------------------------------------
PCT ...PERCENTAGE CHANGE RELATIVE TO PREVIOUS YEAR
PCTB ...PERCENTAGE CHANGE RELATIVE TO BASE YEAR
APCB ...ANNUAL PERCENTAGE CHANGE RELATIVE TO BASE YEAR
```

Annual summary table 3:

```
--------------------------------------------------------------------------------------------------------------------
SUMMARY TABLE OF SELECTED INVESTMENT INDICATORS,
DOUGLAS CNTY, OREGON 1973-1973.
--------------------------------------------------------------------------------------------------------------------
                     PRODUCTION               POLLUTION ABATEMENT                      CAPITAL STOCKS
             ----------------------------  ----------------------------  -------------------------------------------
                                                                                             POLLUTION
YEAR             EXPANSION    REPLACEMENT      EXPANSION    REPLACEMENT     PRODUCTION      ABATEMENT          TOTAL
--------------------------------------------------------------------------------------------------------------------
                    (THOU)         (THOU)         (THOU)         (MILL)         (MILL)         (MILL)         (MILL)
1973                    0.             0.             0.             0.           370.             5.           375.
PCT                 -100.0         -100.0         -100.0         -100.0           -1.8           -3.9           -1.9
PCTB               -100.00        -100.00        -100.00        -100.00          -1.83          -3.89          -1.86
APCB               -100.00        -100.00        -100.00        -100.00          -1.83          -3.89          -1.86
--------------------------------------------------------------------------------------------------------------------
PCT ...PERCENTAGE CHANGE RELATIVE TO PREVIOUS YEAR
PCTB ...PERCENTAGE CHANGE RELATIVE TO BASE YEAR
APCB ...ANNUAL PERCENTAGE CHANGE RELATIVE TO BASE YEAR
```

Annual summary table 4:

```
---------------------------------------------------------------------------------------------------------------------
SUMMARY TABLE OF TOTAL EMPLOYMENT BY OCCUPATION,
DOUGLAS CNTY, OREGON  1973-1973.
---------------------------------------------------------------------------------------------------------------------
             PROFES     MANA-      SALES      CLER-                 OPERA-     NOFARM     SER-
YEAR         SIONAL     GERIAL     WORKER     ICAL       CRAFTS     TIVES      NOMINE     VICE       FARM       TOTAL
---------------------------------------------------------------------------------------------------------------------
1973          2867.      1631.       723.      2999.      4118.      4195.      3781.      3610.       874.    24798.
PCT           -2.0       -2.2       -1.6       -1.8       -4.0       -4.3        -.2       -5.4       -3.3      -3.0
PCTB          -1.96      -2.20      -1.56      -1.84      -4.01      -4.26       -.24      -5.44      -3.32     -3.00
APCB          -1.96      -2.20      -1.56      -1.84      -4.01      -4.26       -.24      -5.44      -3.32     -3.00
---------------------------------------------------------------------------------------------------------------------
PCT ...PERCENTAGE CHANGE RELATIVE TO PREVIOUS YEAR
PCTB ...PERCENTAGE CHANGE RELATIVE TO BASE YEAR
APCB ...ANNUAL PERCENTAGE CHANGE RELATIVE TO BASE YEAR
```

Annual summary table 5:

```
---------------------------------------------------------------------------------------------------------
SUMMARY TABLE OF SELECTED LABOR FORCE INDICATORS,
DOUGLAS CNTY, OREGON 1973-1973.
---------------------------------------------------------------------------------------------------------
                         POPULATION                 MIGRATION                  COMMUTING            TOTAL
                  ----------------------    ----------------------    ----------------------    LABOR
YEAR                 MALE       FEMALE          IN          OUT           IN          OUT        FORCE
------------------------------------------------------------------------------------------------------------
1973                39555.      39272.          0.          188.          0.          0.        29980.
PCT                    .7          .3          -I         -88.5          -I          -I           1.1
PCTB                  .70         .26          -I        -88.49          -I          -I          1.09
APCB                  .70         .26          -I        -88.49          -I          -I          1.09
------------------------------------------------------------------------------------------------------------
PCT ...PERCENTAGE CHANGE RELATIVE TO PREVIOUS YEAR
PCTB ...PERCENTAGE CHANGE RELATIVE TO BASE YEAR
APCB ...ANNUAL PERCENTAGE CHANGE RELATIVE TO BASE YEAR
```

Annual summary table 6:

```
---------------------------------------------------------------------------------------------------
SUMMARY TABLE OF GENERAL ECONOMIC INDICATORS,
DOUGLAS CNTY, OREGON 1973-1973.
---------------------------------------------------------------------------------------------------
                                                                 EARNINGS              LABOR   TOTAL
               POPU    EMPLOY      UN      GROSS                    PER      LOCAL     FORCE   LABOR
YEAR          LATION    MENT    EMPLOYED  OUTPUT   EXPORT    PCE    PERSON   DEMAND     RATE   FORCE
---------------------------------------------------------------------------------------------------
              (THOU)   (THOU)   (THOU)   (MILL)   (MILL)   (MILL)   (NO.)    (MILL)    (PCT)  (THOU)
1973            79.      24.8      5.2     686.    300.7    172.7   2007.    213.8    53.494  29.980
PCT              .5      -3.0     26.6     -2.4     -3.3     -3.4    -3.7      -.8      -.7     1.1
PCTB            .48     -3.00    26.63    -2.36    -3.32    -3.37   -3.72     -.77     -.69    1.09
APCB            .48     -3.00    26.63    -2.36    -3.32    -3.37   -3.72     -.77     -.69    1.09
---------------------------------------------------------------------------------------------------
PCT ...PERCENTAGE CHANGE RELATIVE TO PREVIOUS YEAR
PCTB ...PERCENTAGE CHANGE RELATIVE TO BASE YEAR
APCB ...ANNUAL PERCENTAGE CHANGE RELATIVE TO BASE YEAR
```

Parameters

The values for each parameter in the model can be viewed when IPASS asks:

```
WOULD YOU LIKE TO MODIFY (year) PARAMETERS?
```

If the user responds "yes," IPASS will ask:

```
WHAT PARAMETERS WOULD YOU LIKE TO MODIFY?
```

The user then keys the number corresponding to the parameter. A complete list of parameters is in appendix C, table 5. For each parameter specified, IPASS will ask:

```
HOW WOULD YOU LIKE TO MODIFY (parameter)?
```

Keying an "8" will command IPASS to print the values for each parameter specified. Appendix B discusses the parameter change routine.

In the following example we will look at the parameter called employment by sector (#55 in table 5).

```
 DO YOU WANT TO MODIFY THE 1973 SIMULATION?
 [YES OR NO]
? yes
 Y

 WHAT PARAMETERS DO YOU WANT TO MODIFY?
 TYPE UP TO TEN NUMBERS [1-120]
? 55
 55

 HOW DO YOU WANT TO MODIFY
 55:  EMPLOYMENT BY SECTOR
? 8
 8
 CURRENT PARAMETER PRINTOUT
  1 LOGGING          2935.00000
  2 SAWMILLS         1885.00000
  3 PLY&VENEER       3525.00000
  4 FIBER PROD        593.00000
  5 FISHING           265.00000
  6 CROPS             705.00000
  7 LIVESTOCK         403.00000
  8 MANUFACTUR       1580.00000
  9 LODGING           476.00000
 10 EATERIES         1129.00000
 11 SERV STA          427.00000
 12 CAR DEALER        567.00000
 13 COM,TRAN,U       1011.00000
 14 PROF SERV         813.00000
 15 FINANCIAL         310.00000
 16 CONSTRUCT        1047.00000
 17 TRADE            1878.00000
 18 RET SERV         1017.00000
 19 USFS SALES           .00000
 20 BLM SALES            .00000
 21 USFS APPRO        459.00000
 22 BLM APPRO         140.00000
 23 CNTY GOVT        3095.00000
 24 CITY GOVT         171.00000
 25 ADMIN GOVT       1135.00000

THE TOTAL IS ...    25566.00000
```

Optional Output

Some IPASS output is more specialized and is intended to allow a programer to find and correct errors in the model. Should the user want to see any optional output, he or she would respond with a "yes" to the following question:

```
DO YOU WANT TO USE OPTIONAL IPASS PROGRAMMING?
```

The user may select different options. A discussion and an example for each follows.

```
1. DO YOU WANT TO SEE CALCULATIONS
   FOR THE CONVERSION OF INVESTMENT TO GPCF?
```

The calculations transforming capital investment by sector into final demand purchases of capital goods from producing sectors are:

```
   I   J   INVMAT  X  AINV  =  GPCF(PARTIAL)
--------------------------------------------
   2   6   .00009       0.        0.
   2  13   .00007       0.        0.
   8   1   .05740       0.        0.
   8   2   .05740       0.        0.
   8   3   .05740       0.        0.
   8   4   .03360       0.        0.
   8   5   .00371       0.        0.
   8   8   .06782       0.        0.
   8   9   .00140       0.        0.
   8  10   .00145       0.        0.
   8  11   .01275       0.        0.
   8  12   .00791       0.        0.
   8  13   .00192       0.        0.
   8  14   .00402       0.        0.
   8  15   .00033       0.        0.
   8  16   .40621       0.        0.
   •   •      •         •         •
   •   •      •         •         •
   •   •      •         •         •
  17   1   .09109       0.        0.
  17   2   .09109       0.        0.
  17   3   .09109       0.        0.
  17   4   .07698       0.        0.
  17   5   .11073       0.        0.
  17   6   .08710       0.        0.
  17   7   .29003       0.        0.
  17   8   .06444       0.        0.
  17   9   .05081       0.        0.
  17  10   .12800       0.        0.
  17  11   .09997       0.        0.
  17  12   .10880       0.        0.
  17  13   .03092       0.        0.
  17  14   .08378       0.        0.
  17  15   .10827       0.        0.
  17  16   .13216       0.        0.
  17  17   .08578       0.        0.
  17  18   .02984       0.        0.
  18   5   .00015       0.        0.
  18   6   .00007       0.        0.
  18   7   .00048       0.        0.
  18  18   .00950       0.        0.
```

where:

I = the sector investing,

J = the sector producing capital goods,

$INVMAT_{ji}$ = the percentage of the total investment by sector i purchased from sector j,

GPCF = the running total of capital items bought from sector j by each purchasing sector i. The total is the final demand gross private capital formation (GPCF). The equation is:

$$GPFC_j = \sum_{i=1}^{NIS} INVMAT_{ji} \times AINV_i$$

for each sector j, summing from 1 to the number of sectors (NIS), and

$AINV_i$ = the total investment for i.

```
2. DO YOU WANT TO PRINT OUT COMPONENTS
   OF THE PCE CALCULATIONS?
```

Personal consumption expenditures (PCE) and parameters used to determine PCE for each sector are printed as follows:

```
SEC   PCE1      PCE       PT       PI     ELASIN     PIT      DIT    PCESUBT    PCET
------------------------------------------------------------------------------------------
 1      35.       35.   .98678   .97802   .00000  163531.  140637.      35.  163153.
 2     265.      261.   .98678   .97802   .00000  163531.  140637.     296.  163153.
 3     714.      705.   .98678   .97802   .00000  163531.  140637.    1001.  163153.
 4       0.        0.   .98678   .97802   .00000  163531.  140637.    1001.  163153.
 5      31.       30.   .98678   .97802   .00000  163531.  140637.    1031.  163153.
 6     144.      141.   .98678   .97802   .30000  163531.  140637.    1172.  163153.
 7     144.      142.   .98678   .97802   .05000  163531.  140637.    1315.  163153.
 8     798.      782.   .98678   .97802   .35000  163531.  140637.    2096.  163153.
 9    1558.     1486.   .98678   .97802  1.50000  163531.  140637.    3583.  163153.
10    8527.     8133.   .98678   .97802  1.50000  163531.  140637.   11716.  163153.
11   12060.    11728.   .98678   .97802   .65000  163531.  140637.   23444.  163153.
12   32316.    31534.   .98678   .97802   .50000  163531.  140637.   54978.  163153.
13   10936.    10447.   .98678   .97802  1.43000  163531.  140637.   65425.  163153.
14    9939.     9596.   .98678   .97802   .97000  163531.  140637.   75021.  163153.
15    6844.     6569.   .98678   .97802  1.22500  163531.  140637.   81590.  163153.
16    6250.     6167.   .98678   .97802   .00000  163531.  140637.   87757.  163153.
17   64165.    61412.   .98678   .97802  1.35000  163531.  140637.  149169.  163153.
18   14303.    13957.   .98678   .97802   .50000  163531.  140637.  163126.  163153.
19      51.       50.   .98678   .97802   .00000  163531.  140637.  163177.  163153.
20      12.       12.   .98678   .97802   .00000  163531.  140637.  163189.  163153.
21       0.        0.   .98678   .97802   .00000  163531.  140637.  163189.  163153.
22       0.        0.   .98678   .97802   .00000  163531.  140637.  163189.  163153.
23    7894.     7790.   .98678   .97802   .00000  163531.  140637.  170978.  163153.
24    1737.     1714.   .98678   .97802   .00000  163531.  140637.  172692.  163153.
```

where:

SEC = sector number,

PCE1 = personal consumption expenditures PCE for the previous iteration (year),

PCE = personal consumption expenditures for the current year,

PT = ratio of last year's total population to that of the previous year,

PI = ratio of last year's total disposable income per worker to that of the previous year,

ELASIN = the income elasticity of demand,

PIT = total personal income,

DIT = total disposable income,

PCESUBT = personal consumption expenditures for local goods, and

PCET = total personal consumption expenditure.

3. `DO YOU WANT TO VIEW THE CHANGE IN GROSS OUTPUT RESULTING FROM "USER-SPECIFIED FINAL DEMANDS"?`

The user may introduce a change in final demand through the "special" parameter called user-specified final demand. By responding "yes" to this question, the user may see the change in gross output associated with the user-specified final demand using traditional I/O analysis; for example, the Leontief demand multipliers. In this example, a user-specified final demand of $1,000 in sector 1 resulted in a change of regional output by local sectors of $1,478.299. In the simulation model, this change in regional output will be subject to labor constraints and output capacities.

```
DIRECT AND INDUCED OUTPUT RESULTING
FROM USER SPECIFIED FINAL DEMAND
SECTOR                      OUTPUT
-----------------------------------
   1                      1029.212
   2                         3.425
   3                         8.476
   4                          .002
   5                         1.868
   6                          .027
   7                          .321
   8                        22.996
   9                          .034
  10                          .041
  11                        28.990
  12                       110.876
  13                        42.045
  14                         5.704
  15                        49.545
  16                        10.629
  17                        38.578
  18                        15.841
  19                        11.651
  20                        61.236
  21                         0.000
  22                         0.000
  23                        35.676
  24                         1.125
  25                         0.000
TOTAL =                   1478.299
```

4. DO YOU WANT TO SEE THE LEONTIEF INVERSE CALCULATIONS THAT DETERMINE GROSS OUTPUT DEMANDED?

Output demanded is calculated using the Leontief matrix equation:

$X = [I-A]^{-1} Y$

where:

Y = FD (total final demands),

$[I-A]^{-1}$ = LEMAT (the Leontief inverse), and

X = XD (gross regional output demanded).

This option prints the value for these variables as well as the running total for gross regional output demanded:

$$XD_i = \sum_{j=1}^{24} LEMAT_{ij} \times FD_j$$

The following example shows the XD calculation for sector 3 (i.e., i = 3).

```
FOR WHAT SECTOR DO YOU WANT TO CHECK THE
LEONTIEF INVERSE CALCULATION?
 TYPE THE SECTOR NUMBER
? 3
   3

   I   J     LEMAT       FD(J)   XD(SUMMED)
 ------------------------------------------
    3   1 .00847574     21147.       179.
    3   2 .02398027     42565.      1200.
    3   31.02326856    148021.    152666.
    3   4 .00025677     43897.    152677.
    3   5 .00025502       310.    152677.
    3   6 .00032231      3681.    152678.
    3   7 .00096332      4584.    152683.
    3   8 .00013266     45617.    152689.
    3   9 .00064549      3993.    152691.
    3  10 .00014086      9639.    152693.
    3  11 .00001098     17197.    152693.
    3  12 .00000547     37755.    152693.
    3  13 .00001185     17075.    152693.
    3  14 .00003662     12184.    152694.
    3  15 .00006864     10281.    152694.
    3  16 .00035165     11957.    152699.
    3  17 .00111440     72274.    152779.
    3  18 .00002452     23855.    152780.
    3  19 .11687999      6190.    153503.
    3  20 .11887123      1896.    153728.
    3  21 .00227672      9468.    153750.
    3  22 .00196513      1674.    153753.
    3  23 .00008635     19479.    153755.
    3  24 .00009719      2535.    153755.
 DO YOU WANT TO LOOK AT ANY OTHER SECTOR?
 [YES OR NO]
? no
 N
```

5. DO YOU WANT TO SEE A COMPARISON OF ACTUAL OUTPUT AND OUTPUT DEMANDED BY SECTOR?

Regional output is constrained by both production capacity and shortage of labor. This option provides a comparison of (1) the estimated regional output based on the production constraint and, (2) the estimated regional output, constrained by both production and labor. The first tabulation provides regional gross outputs (XD) as required by final demands, regional output capacity (XS), and the adjusted gross output (X). 'Adjustment" is the difference between the output for which there was demand as determined by final demand, and the actual regional output constraints placed on the producing sectors.

```
SEC         X          XD          XS    ADJUSTMENT
-------------------------------------------------------
 1       38990.     45431.     39362.       6441.
 2       42584.     44802.     42616.       2218.
 3      130612.    153755.    130625.      23143.
 4       39778.     43901.     39778.       4123.
 5        4063.      4456.      4113.        393.
 6        3504.      3766.      3505.        262.
 7        5644.      5684.      5685.         41.
 8       48393.     50959.     48460.       2565.
 9        3826.      4056.      3826.        230.
10        9278.      9692.      9278.        414.
11       20086.     21322.     20129.       1236.
12       44145.     48438.     44274.       4293.
13       25490.     27999.     25632.       2508.
14       11829.     13663.     11841.       1834.
15       25819.     27830.     26389.       2011.
16       26122.     27555.     26650.       1433.
17       85805.     93976.     86044.       8171.
18       29306.     31445.     29389.       2139.
19       16618.     18327.     18000.       1709.
20       16525.     18939.     18000.       2414.
21        9468.      9468.      9468.          0.
22        1674.      1674.      1674.          0.
23       32295.     33826.     33826.       1531.
24        4195.      4375.      4375.        180.
TOT     686115.    755406.    693008.
```

The second tabulation provides readjusted regional gross outputs (X) as constrained by available labor output (XL). XHOLD is equal to X from the first tabulation:

```
SEC          X       XHOLD        XL     ADJUSTMENT
-----------------------------------------------------
 1       38990.     38990.     38990.         0.
 2       42584.     42584.     42584.         0.
 3      130612.    130612.    130612.         0.
 4       39778.     39778.     39778.         0.
 5        4063.      4063.      4063.         0.
 6        3504.      3504.      3504.         0.
 7        5644.      5644.      5644.         0.
 8       48393.     48393.     48393.         0.
 9        3826.      3826.      3826.         0.
10        9278.      9278.      9278.         0.
11       20086.     20086.     20086.         0.
12       44145.     44145.     44145.         0.
13       25490.     25490.     25490.         0.
14       11829.     11829.     11829.         0.
15       25819.     25819.     25819.         0.
16       26122.     26122.     26122.         0.
17       85805.     85805.     85805.         0.
18       29306.     29306.     29306.         0.
19       16618.     16618.     16618.         0.
20       16525.     16525.     16525.         0.
21        9468.      9468.      9468.         0.
22        1674.      1674.      1674.         0.
23       32295.     32295.     32295.         0.
24        4195.      4195.      4195.         0.
TOT     686115.    686115.    686115.
```

where:

SEC = sector number;

X = adjusted regional output;

XD = gross regional output demanded by final demand;

XS = output capacity of the region's capital stock;

ADJUSTMENT = XD minus X in the first tabulation,

= XHOLD minus X in the second tabulation;

XHOLD = adjusted regional output constrained by production; and

XL = the portion of XHOLD for which labor is available--that is, the maximum output as constrained by labor.

```
6. DO YOU WANT TO SEE THE OCCUPATIONAL EMPLOYMENT DATA?
```

Data are provided on employment, commuting, and migration for each occupation:

```
          PROFES  MANA-   SALES   CLER-          OPERA-  NOFARM  SER-
          SIONAL  GERIAL  WORKER  ICAL    CRAFTS TIVES   NOMINE  VICE    FARM
-----------------------------------------------------------------------------
EMPLOYS   3384.   2230.   1486.   3501.   4615.   5673.   3984.   4150.   1009.
EMPLOYD   2867.   1631.    723.   2999.   4118.   4195.   3781.   3610.    874.
ACTEMP    2867.   1631.    723.   2999.   4118.   4195.   3781.   3610.    874.
COMIN       0.      0.      0.      0.      0.      0.      0.      0.      0.
COMOUT      0.      0.      0.      0.      0.      0.      0.      0.      0.
OTMIGOC     5.      6.      8.      5.      5.     15.      2.      5.      1.
INMIGOC     0.      0.      0.      0.      0.      0.      0.      0.      0.
LBFOCUR .112719 .074177 .049299 .116603 .153767 .188720 .132833 .138255 .033626
```

where:

EMPLOYS = number of workers available by occupation,

EMPLOYD = number of workers demanded by sector by occupation,

ACTEMP = estimated number of workers employed by occupation,

COMIN = number of workers commuting in,

COMOUT = number of workers commuting out,

OTMIGOC = number of workers migrating out,

INMIGOC = number of workers migrating in, and

LBFOCUR = percentage distribution of labor force to each occupation.

```
7. DO YOU WANT TO SEE POPULATION AND
   MIGRATION DATA BY ONE-YEAR AGE CLASSES?
```

Data are provided on population and number of persons migrating in and out. Data are categorized by sex and 1-year age classes from age 1 to 66 and above:

```
 I     POPM      INMIGM    OUTMIGM     POPF      INMIGF    OUTMIGF
--------------------------------------------------------------------
 1     644.2        .0         .0      606.6        .0         .0
 2     642.2        .0         .0      604.7        .0         .0
 3     546.6        .0         .0      516.0        .0         .0
 4     590.4        .0         .0      573.8        .0         .0
 5     573.5        .0         .0      557.9        .0         .0
 6     535.6        .0        2.2      586.7        .0        2.0
 7     598.5        .0        2.2      609.8        .0        2.0
 8     565.5        .0        2.2      602.8        .0        2.0
 9     804.4        .0        2.2      717.8        .0        2.0
10     810.4        .0        2.2      743.8        .0        2.0
11     902.3        .0        2.0      815.8        .0        2.0
12     880.5        .0        2.0      803.8        .0        2.0
13     854.5        .0        2.0      853.8        .0        2.0
14     910.5        .0        2.0      878.8        .0        2.0
15     860.5        .0        2.0      846.8        .0        2.0
16     901.5        .0        2.3      842.8        .0        2.5
17     924.8        .0        2.3      860.9        .0        2.5
18     908.9        .0        2.3      877.9        .0        2.5
19     891.9        .0        2.3      838.9        .0        2.5
20     814.8        .0        2.3      776.2        .0        2.5
21     771.1        .0        3.3      776.9        .0        3.3
22     639.4        .0        3.3      597.2        .0        3.3
23     411.9        .0        3.3      539.3        .0        3.3
24     370.0        .0        3.3      491.3        .0        3.3
25     410.9        .0        3.3      503.3        .0        3.3
26     431.6        .0        1.7      517.5        .0        1.8
27     433.6        .0        1.7      519.8        .0        1.8
28     444.6        .0        1.7      530.8        .0        1.8
29     471.5        .0        1.7      508.8        .0        1.8
30     471.5        .0        1.7      508.8        .0        1.8
31     471.5        .0        1.4      507.8        .0        1.3
32     470.9        .0        1.4      508.3        .0        1.3
33     473.9        .0        1.4      512.3        .0        1.3
34     447.9        .0        1.4      470.3        .0        1.3
35     447.9        .0        1.4      470.3        .0        1.3
36     447.9        .0        1.1      470.3        .0        1.1
37     446.4        .0        1.1      469.1        .0        1.1
38     447.4        .0        1.1      470.1        .0        1.1
39     436.4        .0        1.1      452.1        .0        1.1
40     436.4        .0        1.1      452.1        .0        1.1
41     436.4        .0        1.1      451.1        .0        1.0
42     436.4        .0        1.1      451.2        .0        1.0
43     435.4        .0        1.1      452.2        .0        1.0
44     470.3        .0        1.1      455.2        .0        1.0
45     470.3        .0        1.1      455.2        .0        1.0
46     470.3        .0         .8      455.2        .0         .8
47     467.3        .0         .8      454.2        .0         .8
48     467.3        .0         .8      453.2        .0         .8
49     459.3        .0         .8      465.2        .0         .8
50     459.3        .0         .8      465.2        .0         .8
51     459.3        .0         .8      465.2        .0         .8
52     458.3        .0         .8      464.2        .0         .8
53     458.3        .0         .8      464.2        .0         .8
54     448.4        .0         .8      428.3        .0         .8
55     448.4        .0         .8      428.3        .0         .8
56     448.4        .0         .6      427.3        .0         .6
57     443.3        .0         .6      425.3        .0         .6
58     440.3        .0         .6      425.3        .0         .6
59     393.3        .0         .6      385.7        .0         .6
60     393.3        .0         .6      384.7        .0         .6
61     393.3        .0         .6      384.7        .0         .6
62     392.3        .0         .6      384.7        .0         .6
63     392.3        .0         .6      384.7        .0         .6
64     337.5        .0         .6      326.3        .0         .6
65     336.5        .0         .6      326.3        .0         .6
66    3912.1        .0        4.5     4099.0        .0        6.0
```

where:

POPM = population of males,

INMIGM = number of males migrating in,

OUTMIGM = number of males migrating out,

POPF = population of females,

INMIGF = number of females migrating in,

OUTMIGF = number of females migrating out.

8.
```
DO YOU WANT TO PRINT OUT COMPONENTS
OF BUSINESS INCOME CALCULATIONS?
```

Statistics on business income and depreciation are provided for each sector:

```
SEC    X      VALUEAD  BUSINC   NBUSINC(I)  ACNETBI  CADEPR    CADEPA
-----------------------------------------------------------------------
 1    42756.    16273.     4379.     2473.     2059.      990.        0.
 2    44710.    13479.     3741.     2141.     1365.     1556.        0.
 3   144832.    50820.    11318.     4705.     -885.     2540.      137.
 4    42062.     5512.     1089.      951.    -3289.     1716.       92.
 5     4172.     1828.      219.      153.      -27.      104.        0.
 6     3617.      377.      144.      130.      213.        0.        0.
 7     5666.     1362.      666.      583.     1435.        0.        0.
 8    49139.    11870.     3674.      859.     1266.        3.        0.
 9     4015.      844.      298.      203.      510.        0.        0.
10     9589.     3654.      808.      370.      898.        0.        0.
11    21186.     3067.      443.       84.     -305.        1.        0.
12    47403.     6203.      857.      276.    -1001.      206.        0.
13    28010.    12393.     4726.     1910.    -1170.        1.        0.
14    13419.     8851.     1781.      114.     -208.        0.        0.
15    27192.     3527.      786.       86.     -133.        0.        0.
16    29659.     8283.     1740.      781.    -1061.        1.        0.
17    92305.    17560.     3805.     1161.    -2662.        2.        0.
18    31076.     9122.     1370.      615.      692.        0.        0.
19    17620.    10757.    10757.        0.        0.        0.        0.
20    17714.    12163.    12163.        0.        0.        0.        0.
21     9463.     4778.        3.        3.        1.        0.        0.
22     1673.     1245.        4.        4.        3.        0.        0.
23    33191.    20398.     1684.       -1.        1.        0.        0.
24     4320.     1453.      407.        7.       22.        0.        0.
25    10060.    10060.       -2.       -2.        0.        0.        0.
```

where:

SEC = sector number;

X = regional output;

VALUEAD = value added, excluding imports;

BUSINC = business income (equal to value added minus employee earnings);

NBUSINC = net business income (equal to business income minus indirect taxes);

ACNETBI = accumulated net business income (equal to the sum of net business incomes minus depreciation over time);

CADEPR = depreciation of production capital; and

CADEPA = depreciation of pollution abatement equipment.

9. DO YOU WANT TO SEE WHICH SECTORS NEEDED TO BORROW OR FREEZE EARNINGS TO REMAIN VIABLE?

If the user responds "yes," IPASS will print the following statement for each sector that did not make enough profit to pay taxes and its employees:

```
SECTOR   11,   SERV STA NEEDED TO BORROW $  12111.55 AND
100 PERCENT OF ITS DEPRECIATION ALLOWANCE TO PAY WAGES
AND BUSINESS TAXES.
```

Appendix B: How To Modify Parameters

A parameter is any set of values in the data base; sometimes it can be a single value. The user is given an opportunity to modify parameters when IPASS asks:

```
DO YOU WANT TO MODIFY THE (year+1) SIMULATION?
```

If the user responds "yes," another question will follow:

```
WHAT PARAMETERS DO YOU WANT TO MODIFY?
```

A list of parameters appears in table 5, appendix C. The user should key the number corresponding to the parameter(s) to be modified (for example; "15,16"). After the user presses the "return" key, IPASS will ask:

```
HOW DO YOU WANT TO MODIFY

#:  (parameter name)
```

The user may modify a single value within the parameter, all values, or simply view the values within the parameter and make no modification. Also, if the simulation must be aborted, the user can stop it at this time.

There are nine types of modification:

1 = Add a value to an existing, individual value within the parameter
2 = Replace the value of an existing, individual
3 = Change the value of an existing, individual value by percentage
4 = Add a value to an existing total for all values within a parameter
5 = Replace the existing total for all values
6 = Change the existing total for all values by a percentage
7 = Stop the simulation
8 = Display the values of the parameter
0 = No modification.

To specify the type of modification to be made and new values, the user responds with a 3- or 4-part code. Table 4, appendix B, explains the response code for each type of modification.

When keying the code, the user must also identify the dimension of the parameter being modified: scalar, vector, or matrix. A scalar contains only one row and one column, a single value. A vector contains one column of values in multiple rows. A matrix contains multiple columns of values in multiple rows. Figure 5 shows an example of each dimension. The user can determine the dimension of the parameter he or she is modifying by consulting the characteristics of IPASS parameters listed in table 5, appendix C.

IPASS also allows the user to modify "special parameters" during the simulation:

```
DO YOU WANT TO MODIFY "SPECIAL" INVESTMENT PARAMETERS FOR
(year+1)?
```

```
DO YOU WANT TO MODIFY "SPECIAL" FINAL DEMAND PARAMETERS FOR
(year+1)?
```

If the user responds "yes" to either question, IPASS will immediately print a list of the special parameters. IPASS then asks:

```
WHAT PARAMETERS DO YOU WANT TO MODIFY?
```

The user then keys the number from the list that corresponds to the desired parameter. IPASS then asks:

```
HOW DO YOU WANT TO MODIFY

#: (parameter name)
```

To specify the type of modification to be made and new values, the user responds with the appropriate 3- or 4-part code explained in table 4.

When the user completes modification of a parameter, he or she will enter "0," signifying no more modifications.

A. Scalar

The single-value parameter is in row 1, column 1.

Male-Female Birth Ratio
.515000

B. Vector

The parameter circled is in row 6, column 1.

SECTOR		
NO.	NAME	EMPLOYMENT
		(NO.)
1	LOGGING	2935.
2	SAWMILLS	1885.
3	PLY&VENEER	3525.
4	FIBER PROD	593.
5	FISHING	265.
6	CROPS	705.
7	LIVESTOCK	403.
8	MANUFACTUR	1580.
9	LODGING	476.
10	EATERIES	1129.
11	SERV STA	427.
12	CAR DEALER	567.
13	COM,TRAN,U	1011.
14	PROF SERV	813.
15	FINANCIAL	310.
16	CONSTRUCT	1047.
17	TRADE	1878.
18	RET SERV	1017.
19	USFS SALES	0.
20	BLM SALES	0.
21	USFS APPRO	459.
22	BLM APPRO	140.
23	CNTY GOVT	3095.
24	CITY GOVT	171.
25	ADMIN GOVT	1135.

C. The parameter circled is in row 4, column 3.

Annual Rate of Change
in Labor Force Participation
Rate by Males

Age Class	1970-79	1980-84	1985-89	1990+
1-13	0.000000	0.000000	0.000000	0.000000
14-15	0.000000	0.000000	0.000000	0.000000
16-17	.006237	.005650	.005650	.005650
18-19	.008717	.000547	.000547	.000547
20-24	-.001622	.002548	.002548	.002548
25-29	-.002288	-.000105	-.000105	-.000105
30-34	-.002288	-.000105	-.000105	-.000105
35-44	-.002487	-.000522	-.000522	-.000522
45-54	-.004710	-.001743	-.001743	-.001743
55-59	-.011666	-.005996	-.005996	-.005996
60-64	-.026130	-.014735	-.014735	-.014735
65+	-.041339	-.025202	-.025202	-.025202

Figure 5.--Parameter modifications may involve a scalar (A), vector (B), or matrix (C). A scalar has one row and one column, a vector has multiple rows and one column, and a matrix has multiple rows and multiple columns.

Table 4--How to modify parameters during IPASS simulation

Code and type of modification	User response code	IPASS display after user response
Either indicate how individual values of parameters are to be modified:		
1 = Add a value Z (Z may be negative).	1,X,Y,Z [RETURN] (1 is the code for this type of modification, X is the row in which the parameter appears, Y is the column in which the parameter appears, and Z is the amount to be added.	SECTOR XX,XX WAS XXX.XX IS XXX.XX ? (The question mark signifies that IPASS is ready for another modification of the same parameter. To end modification, see response code 0.)
2 = Replace the value.	2,X,Y,Z [Return] (2 is the code for this type of modification, X is the row in which the parameter appears, Y is the column in which the parameter appears, and Z is the replacement value.)	SECTOR XX,XX WAS XXX.XX IS XXX.XX ?
3 = Change by a percentage.	3,X,Y,Z [Return] (3 is the code for this type of modification, X is the row in which the parameter appears, Y is the column in which the parameter appears, and Z is the percentage change.)	SECTOR XXX,XX WAS XXX.XX IS XXX.XX ?
Or indicate how the total of a parameter is to be changed (IPASS distributes the appropriate proportion to all values within the parameter):		
4 = Increase the total amount Z. (Each value within the parameter will be increased by: $\frac{V_{xy}}{\Sigma V_{xy}} * Z$ where V_{xy} is the value of the parameter element X in column Y before the change, and ΣV_{xy} is the sum of all X elements in column Y before the change.)	4,Y,Z [Return] (4 is the code for this type of modification, Y is the column in which the parameter appears, and Z is the amount to be added to the total.)	SECTOR 1,XX WAS XXX.XX IS XXX.XX SECTOR 2,XX WAS XXX.XX IS XXX.XX SECTOR XX,XX WAS XXX.XX IS XXX.XX THE TOTAL WAS XXX.XX IS XXX.XX ?

Table 4-- How to modify parameters during IPASS simulation--Continued

Code and type of modification	User response code	IPASS display after user response
5 = Replace the total with value Z. (Each value within the parameter will be changed by: $\frac{V_{xy}}{\Sigma V_{xy}} * Z$ where V_{xy} is the value of the parameter element X in column Y before the change, and ΣV_{xy} is the sum of all X elements in column Y before the change.)	5,Y,Z [Return] (5 is the code for this type of modification, Y is the column in which the parameter appears, and Z is the replacement valued.)	SECTOR 1,XX WAS XXX.XX IS XXX.XX SECTOR 2 ,XX WAS XXX.XX IS XXX.XX SECTOR XX,XX WAS XXX.XX IS XXX.XX THE TOTAL WAS XXX.XX IS XXX.XX ?
6 = Change the total by a percentage. (Each value within the parameter will also changed by percentage Z.)	6,Y,Z [RETURN] (6 is the code for this type of modification, Y is the column in which the parameter appears, and Z is the percentage change.)	SECTOR 1,XX WAS XXX.XX IS XXX.XX SECTOR 2,XX WAS XXX.XX IS XXX.XX SECTOR XX.XX WAS XXX.XX IS XXX.XX THE TOTAL WAS XXX.XX IS XXX.XX ?
7 = Stop the IPASS simulations. (To start a new simulation, the user must begin with "attach, ipass.")	7 [Return] (7 is the code for this type of modification.)	XX.XXX CP SECONDS EXECUTION TIME / (To log off the computer, the user must key "bye".)
8 = Display all elements of the parameter.	8 [Return] (8 is the code for this type of modification.)	1. (sector name) XXX.XX 2. (sector name) XXX.XX XX. (sector name) XXX.XX THE TOTAL IS XXX.XX
0 = End modification of the parameter. (IPASS will then display the next parameter user indicated as wanting to modify.)	0 [Return] (0 is the code for this type of modification.)	HOW DO YOU WANT TO MODIFY XX: (parameter name) ? (If this is the last parameter user indicated as wanting to modify, IPASS will ask: DO YOU WANT TO MAKE ANY OTHER PARAMETER MODIFICATIONS?

Appendix C: List of Parameters

Table 5 lists all parameters the user may modify in an IPASS simulation. It also lists characteristics of each parameter: unit of measure, number of rows and columns, and others. The user must know these characteristics when coding modifications to the parameters.

The parameters have been grouped into eight categories: market, investment, final demand, value added, employment, labor force, and production. The number preceding each parameter is the code the user must key when specifying what parameters to modify.

Most parameters are expressed in dollars or number (for example, the number of employees). The dimension of a parameter (number of rows and columns) usually relates to the number of sectors, time periods, or occupations. "Special" parameters are designated in table 5. Parameters that are ratios or annual rates of change are also noted. These parameters will not have units of measure.

Rate-of-change parameters are as follows:

$$a_{t+1} = a_t (1+c);$$

where:

a_{t+1} = the parameter for the year being simulated,

a_t = the parameter for the current year, and

c = IPASS annual rate-of-change parameter.

Table 5--Parameters used in IPASS simulation

	Characteristics of parameter					
Parameter number and name	Unit of measure	No. of rows	No. of columns	Special parameters	Ratio	Annual rate of change
Market parameters:						
1. National gross output	$1,000	NIS [1]	1			
2. Regional exports	$1,000	NIS	1	X		
3. National growth rate		NIS	[2] 5			X
4. Regional market share		NIS	1		X	
5. Rate of change in regional market share		NIS	1			X
Investment parameters:						
6. Replacement investment, production	$1,000	NIS	1	X		
7. Expansion investment, production	$1,000	NIS	1	X		
8. Replacement investment, pollution abatement	$1,000	NIS	1	X		
9. Expansion investment, pollution abatement	$1,000	NIS	1	X		
10. Production capital	$1,000	NIS	1			
11. Pollution abatement capital	$1,000	NIS	1			
12. Production capital/output ratio		NIS	1		X	
13. Pollution abatement capital/output ratio		NIS	1		X	
14. Rate of change for capital/output ratio		NIS	1			X
15. Leverage ratio		NIS	1		X	
16. Liquidity preference		NIS	1		X	
17. Investment matrix		NIS	NIS		X	

See footnotes at end of table.

Table 5--Parameters used in IPASS simulation--Continued

Parameter number and name	Unit of measure	No. of rows	No. of columns	Special para-meters	Ratio	Annual rate of change
	Characteristics of parameter					
Final demand parameters:						
18. Business inventory change (net)	$1,000	NIS	1	X		
19. Gross private capital formation (GPCF)	$1,000	NIS	1	X		
20. Personal consumption expenditures (PCE)	$1,000	NIS	1	X		
21. Total PCE	$1,000	1	1			
22. Total PCE (previous year)	$1,000	1	1			
23. State and local government purchases	$1,000	NIS	1	X		
24. Federal Government purchases	$1,000	NIS	1	X		
25. User-specified final demand	$1,000	NIS	1	X		
26. Total final demand by sector	$1,000	NIS	1			
27. Rate of change for user-specified final demand		NIS	1			X
28. Rate of change for State and local government purchases[3]						
29. Rate of change for Federal Government purchases[3]						
30. Business inventory/output ratio		NIS	1		X	
31. Income elasticity of demand coefficient		NIS	1		X	
Value added parameters:						
32. Value added/output ratio		NIS	1		X	
33. Earnings	$1,000	NIS	1			
34. Earnings per worker	Dollars	NIS	1			
35. Rate of change in earnings per worker		NIS	[2] 5			X
36. Employee compensation[3]						
37. Employee compensation per worker[3]						
38. Rate of change in compensation per worker[3]						
39. Indirect business tax rate		NIS	1		X	
40. Federal business tax rate		NIS	1		X	
41. Net business income	$1,000	NIS	1			
42. Accumulate net business income	$1,000	NIS	1			
43. Rate of change in indirect tax rate		NIS	1			X
44. Regional imports	$1,000	NIS	1			
45. Regional import rate		NIS	1		X	
46. Capital depreciation rate, production		NIS	1		X	
47. Capital depreciation rate, pollution abatement		NIS	1		X	
48. Total personal income	$1,000	1	1			
49. Total personal income (previous year)	$1,000	1	1			
50. Personal income/earnings ratio		1	1		X	
51. Unemployment compensation rate		1	1		X	
52. Transfer payments rate		1	1		X	
53. Proprietal income rate		1	1		X	
54. PCE/savings ratio		1	1		X	

See footnotes at end of table.

Table 5--Parameters used in IPASS simulation--Continued

Parameter number and name	Characteristics of parameter					
	Unit of measure	No. of rows	No. of columns	Special parameters	Ratio	Annual rate of change
Employment parameters:						
55. Employment by sector	No.	NIS	1			
56. Total employment	No.	1	1			
57. Total employment (previous year)	No.	1	1			
58. Output per worker		NIS	1		X	
59. Output per hour worked		NIS	1		X	
60. Rate of change in output per hour worked		NIS	[2] 5		X	
61. Hours worked per week		NIS	1	X		
62. Rate of change in hours worked per week		NIS	1			X
63. Hours worked per year		NIS	1		X	
64. Weeks worked per year		NIS	1		X	
65. Rate of change in weeks worked per year		NIS	1			X
66. Employment supplied by occupation	No.	NOC[4]	1			
67. Employment demanded by occupation	No.	NOC	1			
68. Unemployment by occupation	No.	NOC	1			
69. Total unemployment	No.		1	1		
70. Other State and local government employment	No.		1			
71. Other State and local government employment/PCE ratio		1	1		X	
72. Rate of change in other State and local government employment/PCE ratio		1	1			X
73. Other Federal civilian government employment	No.	1	1			
74. Other Federal civilian government employment/population ratio		1	1		X	
75. Rate of change in other federal civilian employment/population ratio		1	1			X
76. Federal military employment	No.	1	1			
77. Other government final demand distribution		1	[2] 5		X	
78. Industry occupation matrix		NIS	NOC		X	
Labor force parameters:						
79. Total labor force	No.	1	1			
80. Labor force distribution by occupation		NOC	1		X	
81. Labor force by age group	No.		[6] 12	1		
82. Labor force participation rate (male)		[6] 12	1		X	
83. Rate of change in labor force participation rate (male)		[6] 12	[7] 4			X
84. Labor force participation rate (female)		[6] 12	1		X	
85. Rate of change in labor force participation rate (female)		[6] 12	[7] 4			X
Population Parameters:						
86. Population by age (male)	No.	[8] 66	1			
87. Population by age (female)	No.	[8] 66	1			
88. Total population	No.	1	1			
89. Total population (previous year)	No.	1	1			
90. Fertility rate by age (female)	[9]	[8] 66	1		X	

See footnotes at end of table.

Table 5--Parameters used in IPASS simulation--Continued

	Characteristics of parameter					
Parameter number and name	Unit of measure	No. of rows	No. of columns	Special parameters	Ratio	Annual rate of change
91. Rate of change in fertility rate		[8] 66	[7] 4			X
92. Male/female birth ratio		1	1		X	
93. Death rate by age (male)		[8] 66	1		X	
94. Death rate by age (female)		[8] 66	1		X	
95. National migration distribution by age and sex		[8] 66	[10] 2		X	
96. Rate of change in national migration distribution		[8] 66	[10] 2		X	
97. National employee dependent rate		1	1		X	
98. Rate of change in national employee dependent rate		1	1		X	
99. Regional migration distribution by age and sex		[8] 66	[10] 2		X	
100. Rate of change in regional migration distribution		[8] 66	[10] 2			X
101. Regional employee dependent rate		1	1		X	
102. Rate of change in regional employee dependent rate		1	1			X
103. Immigration/local employment deficit ratio by occupation		NOC	1		X	
104. Out-migration/unemployment ratio by occupation		NOC	1		X	
105. Immigration by occupation	No.	NOC	1			
106. Out-migration by occupation	No.	NOC	1			
107. In-commuting	No.	NOC	1			
108. In-commuting in/local employment deficit ratio		NOC	1		X	
109. Rate of change in in-commuting/local employment deficit ratio		NOC	1			X
110. Out-commuting	No.	NOC	1			
111. Out-commuting/unemployment ratio		NOC	1		X	
112. Rate of change in out-commuting/unemployment ratio		NOC	1			X
113. Cohort movement rate by age (male)		[8] 66	1		X	
114. Cohort movement rate by age (female)		[8] 66	1		X	

See footnotes at end of table.

Table 5--Parameters used in IPASS simulation--Continued

Parameter number and name	Characteristics of parameter: Unit of measure	No. of rows	No. of columns	Special parameters	Ratio	Annual rate of change
Production parameters:						
115. Gross regional output (current year)	$1,000	NIS	1			
116. Gross regional output (previous year)	$1,000	NIS	1			
117. Output required by final demands	$1,000	NIS	1			
118. Output constraint by capital stocks	$1,000	NIS	1			
119. Output constraint by labor	$1,000	NIS	1			
120. Leontief (inverse) matrix		NIS	NIS		X	

---

[1] NIS = number of sectors in the regional model, including "administrative government."

[2] Each column represents a different period of time during the simulation: column 1 = 1970-79, column 2 = 1980-84, column 3 = 1985-89, column 4 = 1990-94, column 5 = 1995-99.

[3] Not currently used in IPASS.

[4] NOC = number of occupations defined in the analysis.

[5] Column 1 = State and local government; column 2 = Federal Government.

[6] Each row represents an age group: row 1 = 1-13 years, row 2 = 14-15 years, row 3 = 16-17 years, row 4 = 18-19 years, row 5 = 20-24 years, row 6 = 25-29 years, row 7 = 30-34 years, row 8 = 35-44 years, row 9 = 45-54 years, row 10 = 55-59 years, row 11 = 60-64 years, row 12 = 65 years and older.

[7] Each column represents a different period of time: column 1 = 1970-74, column 2 = 1975-79, column 3 = 1980-84, column 4 = 1985-99.

[8] Each row represents an age: one row for each year from 0-64, and the last row for age 65 years and older.

[9] Number of births per 1,000 women.

[10] column 1 = males, column 2 = females.

Appendix D: Using the OSU Cyber Computer

This appendix will help users not familiar with the Cyber computer at Oregon State University. The appendix contains these procedure guides:

Procedure Guide 1. Logging onto the OSU computer.
Procedure Guide 2. Obtaining IPASS stored in computer memory.
Procedure Guide 3. Obtaining IPASS stored on magnetic tape.
Procedure Guide 4. Interacting with the IPASS program.
Procedure Guide 5. Deleting improper instructions.
Procedure Guide 6. Logging off the OSU computer.

Procedure Guide 1. Logging onto the OSU computer.

The user must have a terminal with either a telephone or a "hard wire" link and an account with the OSU computer center. Each account is given a user number, a password, an account number, and a project name. The project name is often the same as the user number.

Step	Instructions	Input	Function	Display
1	Turn on power for terminal (switch usually located at rear of terminal).			Red light on keyboard.
2	Check to see that terminal is set to communicate with the computer.		Line/Local	
3	Check tranmission speed. It should be set to 300 baud.		300/100	
	If the terminal is "hard wired" (that is, directly connected with the computer), then skip to step 7.			
4	Turn on power for phone coupler (power switch usually located in front).			Red light.
5	Dial computer by phone: (503) 754-3781.			If busy signal, try again. If high pitch, go to step 6.
6	Place receiver in coupler receptacle.			PORT XXXXC -
7	Key name of system.	NOS	Return	(date) (time) NOS 2.0 OSU 552.6
8	Key carriage return.		Return	FAMILY:
9	Key user number.	COHA2C (for example)	Return	PASSWORD
10	Key password.	DOSCH (for example)	Return	TERMINAL:XX, TTY /
	You should now be logged onto the computer. Go to procedure guide 2.			

Procedure Guide 2. Obtaining IPASS stored in computer memory.

Step	Instructions	Input	Function	Display
1	Perform steps 1-10 in procedure guide 1.			
2	Clear all local files from memory.[1]	CLEAR	Return	XX FILES PROCESSED /
3	Access IPASS program.	ATTACH,IPASS	Return	/ or IPASS NOT FOUND
4	If "/," execute program. Go to procedure guide 4.	IPASS	Return	WELCOME TO IPASS (...etc.)
	If "IPASS NOT FOUND," the program is not in computer memory. Go to procedure guide 3.			

---

[1] If your local files are not permanent, you must save them before this step.

Procedure Guide 3. Obtaining IPASS stored on magnetic tape.

IPASS program is stored on a magnetic tape shelved at the OSU computer center. A procedure file instructs the computer operator to mount the tape and copy the necessary files onto the computer memory.

Step	Instructions	Input	Function	Display
1	Access the IPASS procedure file from storage on Olson's and Schallau's account.	GET,PFILE/ UN = BHCQ2C	Return	/ or FILE NOT FOUND.[1]
2[2]	Use procedure file to obtain IPASS files.	BEGIN,IPASS, PFILE	Return	REVERT.IPASS FILES ARE AVAILABLE.
	Go to procedure guide 4.			

---

[1] If "FILE NOT FOUND" is displayed, contact one of the authors of this user manual: Doug Olson (503)757-4901; Con Schallau (503)757-4413; or Wilbur Maki (612)376-3433.

[2] This step may require 2-15 minutes to complete, depending on the number of users logged onto the Cyber computer.

Procedure Guide 4. Interacting with the IPASS program.

Step	Instructions	Input	Function	Display
1	Proceed with interactive program. program.	(Follow directives in this manual: example 1, example 2, appendixes A-C.)		
2	To exit program before completing all program steps ("bail out"):[1]			
	interrupt IPASS program,		Break	*INTERRUPTED*
	then exit program mode.	(Any alphanumeric character)[2]	Return	*TERMINATED* /

---

[1] If you interrupt the program while a table is being printed, some information from the table may be lost.

[2] If you decide not to bail out after pressing "break," simply press "return" without keying any alphanumeric character. IPASS will resume.

Procedure Guide 5. Deleting improper instructions.

Step	Instructions	Input	Function	Display
Before pressing "Return" (in control mode or program mode):				
Method 1--				
1	Backspace over mistake.		Backspace	
2	Key correct input and rekey remainder of response.	(Correct response)	Return	/
Method 2--				
1	Delete entire line.		Esc	*DEL
2	Key correct input.	(Correct input)	Return	
After pressing "return" (in program mode):				
1	Interrupt IPASS program.		Break	*INTERRUPTED*
2	Exit program mode.	(Any alpha-numeric character)	Return	*TERMINATED* /
3	Initiate IPASS program.	IPASS	Return	WELCOME TO IPASS(...etc.)

Procedure Guide 6. Logging off the OSU computer.

Step	Instructions	Input	Function	Display
When user is in program mode:[1]				
1	Interrupt IPASS program.		Break	*INTERRUPTED*
2	Exit program mode.	(Any alpha-numeric character)	Return	*TERMINATED* /
3	Protect computer from unauthorized use.	BYE	Return	
4	Replace phone and turn off power supply to coupler (if phone was used for connection), and turn off power supply to the terminal.			
When user is not in program mode:				
1	Perform steps 3-4 above.			

---

[1] If you are finished with IPASS and do not intend to use the program until the next day or longer, purge the IPASS file. If you do not purge, IPASS will be stored in computer memory as a permanent file. The cost of storing a permanent file is greater than the cost of shelving and retrieving IPASS from the magnetic tape. To purge, input " PURGE,IPASS,IPDCO72,IPMNS70,IPAKS77,IPSEA77[Return] ."

Appendix E: Batch Mode

Although the interactive mode of IPASS is user friendly and convenient, it is also slow. To speed up the simulation, particularly when analyzing a number of different circumstances, the less tedious batch mode should be used. For batch mode, the user creates an input file that will respond to all questions posed by IPASS. When the IPASS program is initiated, it will then read answers from the input file rather than wait for the user to key a response. Figure 6 illustrates an input file; the responses are those we used in the baseline analysis (example 1).

Creating an input file requires using the XEDIT routine of the OSU computer. An XEDIT User's Guide can be purchased from the Milne Computer Center, Oregon State University, Corvallis, OR 97331.

To perform an IPASS analysis in batch mode, the user must first create the input file. The flow chart at the end of this appendix will guide the user in building the list of responses for the file. Then "attach" IPASS by keying:

IPASS,ifn,ofn [Return] ;

where:

ifn = the input file name, and
ofn = the output file name.

```
2
132
6
no
no
no
3
0
0
no
no
no
no
no
no
```

Figure 6.--Example of an input file for IPASS batch mode.

When "ofn" is left blank, the terminal will immediately begin printing IPASS questions and reading answers from the input file. The simulation will proceed as directed by the input file. When the user designates an output file, IPASS prints all questions and results into that file. Shortly, IPASS responds with "XX.XX CPU SECONDS," indicating a successful run. To see the IPASS output, the user can print the output file on either the terminal or one of the high speed printers at the OSU computer center.

To print IPASS output at the terminal, key:

```
REWIND,ofn [RETURN]
COPY,ofn [RETURN].
```

To print output at the OSU computer center, key:

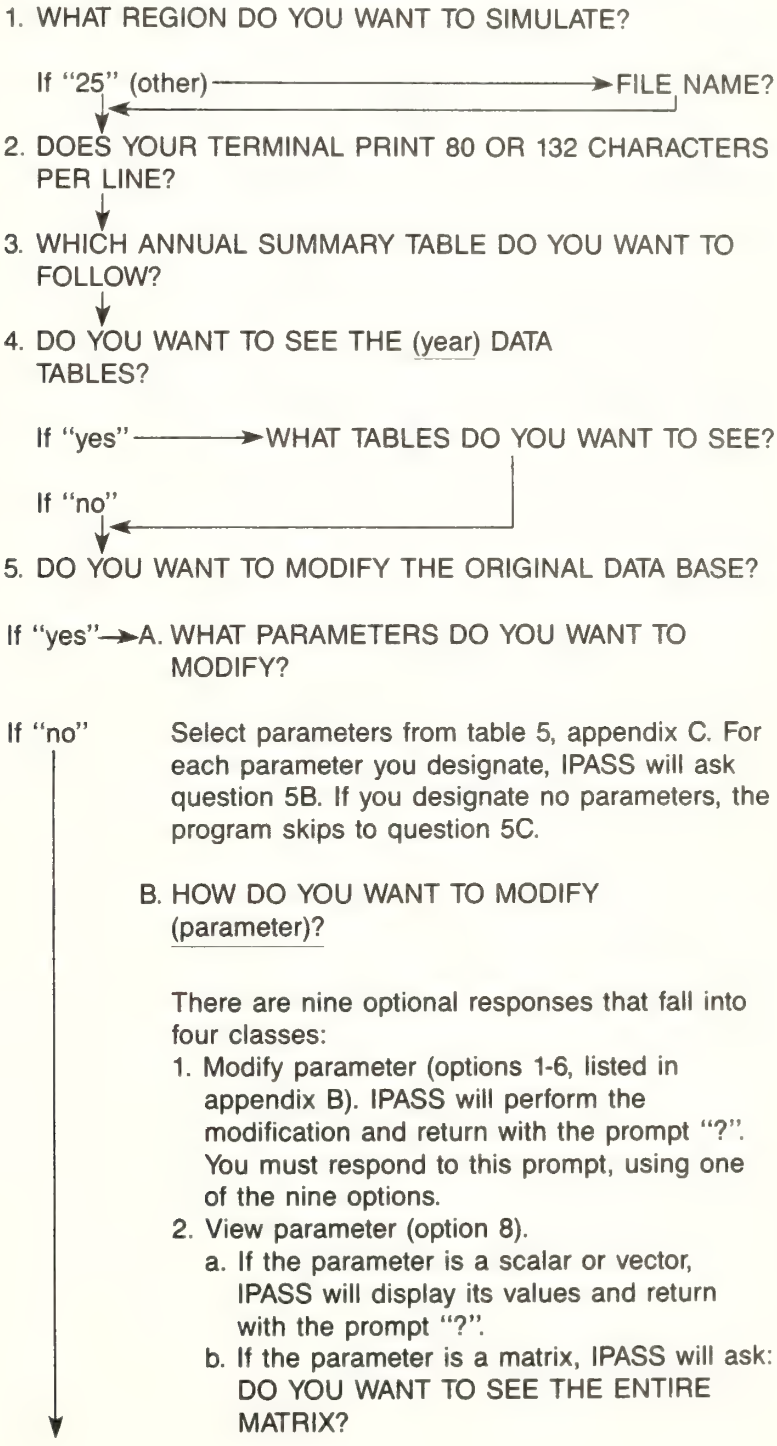
```
REWIND,ofn [RETURN]
TITLE,rfn,DC=LP.(user's last name). [RETURN]
COPYSBF,ofn,rfn [RETURN]
ROUTE,rfn [RETURN]
```

ofn = the output file name, and
rfn = the name of the file to be routed.

The "TITLE" statement prints the user's last name in large block letters so the clerk at the computer center can identify the user's output.

Flow Chart. Questions asked by IPASS, version 3.4.

Questions asked by IPASS are shown in capital letters; user responses are in quotation marks following "if" statements.



1. WHAT REGION DO YOU WANT TO SIMULATE?

If "25" (other) → FILE NAME?

2. DOES YOUR TERMINAL PRINT 80 OR 132 CHARACTERS PER LINE?

3. WHICH ANNUAL SUMMARY TABLE DO YOU WANT TO FOLLOW?

4. DO YOU WANT TO SEE THE (year) DATA TABLES?

If "yes" → WHAT TABLES DO YOU WANT TO SEE?

If "no"

5. DO YOU WANT TO MODIFY THE ORIGINAL DATA BASE?

If "yes" → A. WHAT PARAMETERS DO YOU WANT TO MODIFY?

If "no"

Select parameters from table 5, appendix C. For each parameter you designate, IPASS will ask question 5B. If you designate no parameters, the program skips to question 5C.

B. HOW DO YOU WANT TO MODIFY (parameter)?

There are nine optional responses that fall into four classes:

1. Modify parameter (options 1-6, listed in appendix B). IPASS will perform the modification and return with the prompt "?". You must respond to this prompt, using one of the nine options.
2. View parameter (option 8).
   a. If the parameter is a scalar or vector, IPASS will display its values and return with the prompt "?".
   b. If the parameter is a matrix, IPASS will ask: DO YOU WANT TO SEE THE ENTIRE MATRIX?

If "yes," IPASS will show the entire matrix and return with the prompt "?".

If "no," and the parameter is the "occupational matrix," IPASS will ask: WHICH ROW DO YOU WANT TO SEE? Respond with the row number. IPASS will display the row and return with the prompt "?".

If "no," and the parameter is not the "occupational matrix," IPASS will ask: WHICH COLUMN DO YOU WANT TO SEE? Respond with the column number. IPASS will display the column and return with the prompt "?".

3. Stop simulation (option 7).
4. No modifications or no additional modifications (option 0).

C. DO YOU WANT TO MAKE ANY OTHER PARAMETER MODIFICATIONS?

If "yes," go to question 5A.

If "no'

6. DO YOU WANT TO USE OPTIONAL IPASS PROGRAMMING?

If "yes" → A. DO YOU WANT TO IGNORE CAPITAL CONSTRAINTS?

If "no"

B. DO YOU WANT TO IGNORE OUTPUT PER WORKER?
C. DO YOU WANT TO FREEZE WAGES IN BORROWING SECTORS?
D. DO YOU WANT POLLUTION ABATEMENT CAPACITY CONSTRAINING?
E. DO YOU WANT TO SEE CALCULATIONS FOR THE CONVERSION OF INVESTMENT TO GPCF?
F. DO YOU WANT TO PRINT OUT COMPONENTS OF THE PCE CALCULATIONS?
G. DO YOU WANT TO VIEW THE CHANGE IN GROSS OUTPUT RESULTING FROM "USER-SPECIFIED FINAL DEMANDS"?
H. DO YOU WANT TO SEE THE LEONTIEF INVERSE CALCULATIONS THAT DETERMINE GROSS OUTPUT DEMANDED?

I. DO YOU WANT TO SEE A COMPARISON OF ACTUAL OUTPUT AND OUTPUT DEMANDED BY SECTOR?

J. DO YOU WANT TO SEE THE OCCUPATIONAL EMPLOYMENT DATA?

K. DO YOU WANT TO SEE POPULATION AND MIGRATION DATA BY ONE-YEAR AGE CLASSES?

L. DO YOU WANT TO PRINT OUT COMPONENTS OF BUSINESS INCOME CALCULATIONS?

M. DO YOU WANT TO SEE WHICH SECTORS NEEDED TO BORROW OR FREEZE EARNINGS TO REMAIN VIABLE?

7. HOW MANY YEARS DO YOU WANT TO SIMULATE?

If "0," go to question 15.

8. HOW FREQUENTLY DO YOU WANT TO VIEW DATA TABLES?

9. HOW FREQUENTLY DO YOU WANT TO MODIFY THE SIMULATION?

Simulation begins (or continues). IPASS returns to this point at the end of each year of simulation. Questions 10, 11, and 12 are asked at the first year of simulation and at other years specified in the response to question 9. Question 15 is asked at time intervals specified in response to question 8.

Annual summary table is printed.

If year specified to modify

10. DO YOU WANT TO MODIFY THE (year + 1) SIMULATION?

If "yes" → A. WHAT PARAMETERS DO YOU WANT TO MODIFY?

If not year specified to modify

If "no"

Select parameters from table 5, appendix C. For each parameter selected, IPASS will ask question 10B. If you designate no parameters or when the designated parameters are complete, IPASS skips to question 10C.

B. HOW DO YOU WANT TO MODIFY (parameter)?

The nine optional responses are identified in question 5B.

C. DO YOU WANT TO MAKE ANY OTHER MODIFICATIONS?

If "yes," go to question 10A.

If "no"

If year specified to modify → 11. DO YOU WANT TO MODIFY "SPECIAL" INVESTMENT PARAMETERS FOR (year + 1)?

If "yes" → A. WHICH PARAMETERS DO YOU WANT TO MODIFY [1-4]?

If not year specified to modify

If "no"

Select the number(s) corresponding to the desired parameters from the list IPASS prints:

1. Investment for expanding production capacity
2. Investment for expanding pollution abatement capacity
3. Investment for maintaining production capacity
4. Investment for maintaining pollution abatement capacity

B. HOW DO YOU WANT TO MODIFY (parameter)?

The nine optional responses are identified in question 5B. This question is repeated for each parameter specified in response to question 11A.

If year specified to modify → 12. DO YOU WANT TO MODIFY "SPECIAL" FINAL DEMAND PARAMETERS FOR (year + 1)?

If "yes" → A. WHICH PARAMETERS DO YOU WANT TO MODIFY [1-7]?

If not year specified to modify

If "no"

Select the number(s) corresponding to desired parameters from the list IPASS prints:

1. Personal consumption expenditures
2. Gross private capital formation
3. Inventory change
4. Export
5. State and local expenditures
6. Federal Government expenditures
7. User-specified final demand

B. HOW DO YOU WANT TO MODIFY (parameter)?

The nine optional responses are identified in question 5B. This question is repeated for each parameter specified in response to question 12A.

If question 6 was answered "yes" and option H was indicated → 13. FOR WHAT SECTOR DO YOU WANT TO SEE THE LEONTIEF CALCULATION?

If question 6 was answered "no"

14. DO YOU WANT TO LOOK AT ANY OTHER SECTOR?

If "yes," go to question 13.

If "no'

If final year of simulation, go to question 16.

If not final year of simulation

If year specified to view tables → 15. DO YOU WANT TO SEE THE (year + 1) DATA TABLES?

If "yes," → WHAT TABLES DO YOU WANT TO SEE?

If not year specified to view tables

If "no"

Go to "Simulation begins (or continues)."

16. DO YOU WANT TO SEE THE NEW DATA TABLES?

If "yes," → WHAT TABLES DO YOU WANT TO SEE?

If "no"
↓

17. SAVE (year) DATA BASE FOR FUTURE USE?

If "yes" → UNDER WHAT FILE NAME DO YOU WANT TO SAVE THE DATA?

If "no"
↓

18. CONTINUE SIMULATION?

If "yes," go to question 6.

If "no," simulation ends.

Olson, Doug; Schallau, Con; Maki, Wilbur. IPASS: an interactive policy analysis simulation system. Gen. Tech. Rep. PNW-170. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 70 p.

This paper describes an interactive policy analysis simulation system (IPASS) that can be used to analyze the long-term economic and demographic effects of alternative forest resource management policies. The IPASS model is a dynamic analytical tool that forecasts growth and development of an economy. It allows the user to introduce changes in selected parameters based on different assumptions about socioeconomic variables. The user can analyze the impact those changes would have on the economy by comparing results of the alternative situation with the original forecast. The program is interactive, and the user needs no previous experience in programing or model building. IPASS has potential use in applied research as well as policy analysis.

Keywords: Economic impact, economic theory (-forest management, resource management, Resources Planning Act (RPA), computer programs/programing.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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United States
Department of
Agriculture

Forest Service

Pacific Northwest
Forest and Range
Experiment Station

General Technical
Report
PNW-171
August 1984

Measuring Fuel Moisture Content in Alaska: Standard Methods and Procedures

Rodney A. Norum and Melanie Miller

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Abstract

Norum, Rodney A.; Miller, Melanie. Measuring fuel moisture content in Alaska: standard methods and procedures. Gen. Tech. Rep. PNW-171. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984**. 34 p.

Methods and procedures are given for collecting and processing living and dead plant materials for the purpose of determining their water content. Wild-land fuels in Alaska are emphasized, but the methodology is applicable elsewhere. Guides are given for determining the number of samples needed to attain a chosen precision. Detailed procedures are presented for collecting fuel samples in the field, transporting them safely, and handling them in the laboratory. General guidelines for all live fuels and specific techniques for individual species are given.

Keywords: Fuel moisture content, fuels (forest fire), fire (forest), Alaska.

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Introduction

Almost every facet of modern fire management requires some estimate of fuel moisture content. Recently developed guidelines for prescribed burning call for accurate values for the moisture content of the fuels (Countryman and Dean 1979, Norum 1975). The National Fire Danger Rating System (NFDRS) uses or calculates as many as five fuel moisture contents. Depending on the fuel model involved, the current U.S. Fire Behavior System (Rothermel 1983) may require as many as three integrated dead fuel moisture contents and may also call for a value for live fuels. For calculating fire behavior, the fuel complex involved and the fire behavior and effects sought dictate which fuels must be sampled to determine their moisture content.

Small diameter dead fuels carry the fire and determine the rate of spread and fireline intensity in most cases, so their moisture content is extremely important. Various means and methods have been used to measure or compute dead fuel moisture content. Some analogs have been tried, and one (the standard 1/2-inch diameter fuel moisture indicator sticks described by Fischer and Hardy 1976) is standard equipment at all NFDRS sampling stations. Although some experienced fire managers have found these fuel moisture indicator sticks useful for judging the behavior of planned fires (Morris 1966), others (Beaufait and others 1977, Peck 1969) have shown that there is little correlation between moisture content shown by a fuel stick measurement and that of many natural fuels of similar size collected nearby. The usefulness of fuel moisture sticks must be experimentally determined for any fuel type before they are used as a true direct measure of moisture content and an indirect measure of the flammability of local fuels.

For many reasons, duff, the partially decomposed organic matter on the forest floor, is often sampled for its moisture content. The NFDRS uses duff moisture at a depth of 4 inches and greater below the surface as one measure of 1,000-hour timelag fuels (Deeming and others 1977). Duff moisture content is very important because of the way it influences the impacts and final results of a fire. Many plant parts—rhizomes, roots, tubers—reside in duff. The depth of burning of the duff is instrumental in the survival of many plants and their subsequent resprouting. The burning of the forest floor, as with other fuels, is known to depend on its moisture content (Miller 1977, Norum 1977, Shearer 1975). Readers are encouraged to study the literature and to consult experts on the effects of fire on the ecosystems of interest. The desired depth of burning of the forest floor should be chosen based on this advice; the duff samples most directly related to these important fire effects should then be collected and handled as described.

Although soil is usually not considered to be a fuel, some surface soil samples are often collected for moisture content determination because sprouting parts of many species of plants are concentrated in the surface soil rather than in the duff.

Live plants may either suppress combustion or contribute to it, depending on their moisture content and the flammability of chemical compounds contained in the plant. The NFDRS uses environmental variables to estimate the moisture contents of shrubs and herbaceous plants. These are then used in calculating the ignition component, spread component, and energy release component. Our experience, however, shows that the moisture content of shrubs and herbaceous plants in Alaska is primarily controlled by species physiology and time of year and is little influenced by weather; consequently, it cannot be accurately calculated from such external variables. Data on file at the Institute of Northern Forestry indicate that, although spring weather can alter the date when vegetation breaks dormancy, the moisture content levels and patterns for individual shrub and grass species are essentially the same during both very wet and very dry spring seasons. Patterns vary considerably among species, however.

The moisture content of conifer needles has a marked influence on fire behavior. Norum (1975) in Montana, Stashko and McQueen (1976) in Alberta, and others found that many conifers readily support crown fires in spring. Firefighters have noted that black spruce (*Picea mariana* (Mill.) B.S.P.[1]) trees in Alaska readily support fire whenever flames from surface fires reach into the lower branches. The low moisture content of the needles appears to be determined mainly by species physiology. Data on file at the Institute of Northern Forestry show that black spruce foliar moisture content is not very sensitive to daily weather conditions and, compared with other nondeciduous conifers, is relatively insensitive to seasonal differences. Some differences in moisture content caused by seasonal and site differences do exist, however; because they could have an effect on flammability, particularly late in a fire season, they may be worth monitoring.

In contrast, some live fuels in Alaska are extremely sensitive to short-term changes in weather. The feathermosses and lichens commonly found in the understory of most black spruce forests of interior Alaska quickly respond to changes in relative humidity (Mutch and Gastineau 1970). When these live fuels become dry, they support fire similar to the way finely divided dead fuels do. Because the feathermosses and lichens dry and wet rapidly and because black spruce foliage is almost always in a flammable condition, fire can escalate very quickly in such a fuel complex. Similar feathermosses and lichens are found in some hardwood stands as well as in coastal white spruce (*Picea glauca* (Moench) Voss), western hemlock (*Tsuga heterophylla* Raf. Sarg.), and western red cedar (*Thuja plicata* D. Don) forests. These forest types are generally considered much less flammable than black spruce forests, but in some situations the mosses and lichens are abundant enough to propel a fire through them. Furthermore, even when mosses and lichens are sparse in hardwoods, they are commonly concentrated at the bases of trees, forming a fuel bed that supports a fire of sufficient intensity to kill the trees.

For some fuels, no computational procedure yet developed is adequate to estimate their moisture content. Direct sampling of the fuels is the best alternative. Even when computational procedures are developed, they must mimic the values determined from the field sampling of fuels under various conditions. Regardless of the purpose of fuel moisture sampling, a standard procedure for collecting, processing, and calculating the moisture content of samples is greatly needed. Errors in estimating representative moisture content on a site creep in during every step of the process if a strict regime is not followed. Further, the collection of proper material must be standardized if accurate estimates are to be achieved. Data from many locations could then be compared.

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[1] Taxonomic nomenclature follows that of Hultén.

The purpose of this paper is to present a standard procedure for collecting and handling samples from various fuel complexes, with particular emphasis on selected fuels in Alaska.

The definition of moisture content used here is the ratio of the weight of the water contained to the dry weight of the material, expressed as a percentage. The simple formula is:

$$\frac{\text{(Weight of water in sample)}}{\text{(dry weight of sample)}}(100) = \frac{\text{(sample wet weight} - \text{sample dry weight)}}{\text{sample dry weight}}(100)$$

$$= \text{moisture content in percent.}$$

Sampling Procedure

People Qualified To Collect Fuel Samples

Regardless of the reason for determining fuel moisture content, the sampling must be done to rigid standards. Sloppy sampling and handling procedures can lead to poor results or even serious mistakes. Only trained, skilled people should sample and handle the fuels, and they must strictly adhere to proper procedures. Greater consistency of results is often achieved when the same person does all the sampling on a given area.

Material To Be Collected

The goal is to sample the moisture content of the organic materials that influence the way a fire in those fuels will burn. For some purposes, only fuels influencing the behavior of a fire at its head are of interest. In other cases the effects of the fire are crucial, so fuels leading to impacts on the site are the most important. It is not our goal to give examples in specific fuel complexes or to suggest which fuels to sample. The choice of fuels to sample varies with the reason for sampling and the fuel type. Guidance in choosing the fuels to be sampled may be gained from printed guidelines, previous experience, experts, direct observation, or other sources.

The fuels to be sampled and processed may include one or more of the following:

1. Dead fuels
    a. Small diameter down and dead woody fuel, 0 to 1/4 inch in diameter
    b. Larger (branch wood) down and dead woody fuel, 1/4 to 1 inch in diameter
    c. The partially decomposed organic mat on the surface of mineral soil (commonly called duff)
    d. Dead grasses, forbs, mosses, and lichens
    e. Surface litter, such as fallen leaves and needles

2. Live fuels
    a. Conifer needles
    b. Twigs and leaves of shrubs
        (1) Evergreen
        (2) Deciduous
    c. Green (live) grasses, sedges, and forbs
    d. Mosses
    e. Lichens

Other fuels may be important in some situations, but the sampling and processing procedures described here will be appropriate for almost any fuel complex in Alaska.

When Samples Should Be Collected

For information to be used as input to the National Fire Danger Rating System, fuels must be sampled throughout the fire season, beginning as soon as snow melts in spring and ending late in summer when no possibility of fire remains. The standard time for NFDRS weather observations is at 1400 hours, usually the warmest part of the day. Fuel moisture samples should also be collected at that time. Down and dead woody fuels, litter, and mosses and lichens should be sampled daily because of their quick response to changes in weather. Biweekly sampling is adequate for shrubs, grasses, herbaceous plants, duff, and conifer foliage because of the slower changes in moisture level of these fuels.

The seasonal period and frequency of sampling before prescribed burning is different for each situation, but some guidelines can be given. Some information may be obtained by sampling fuels throughout the fire season 1 or more years before a prescribed fire. Because weather conditions differ markedly among years, however, it is quite possible that the only useful seasonal fuel moisture trends are those of the live fuels. If the fire must be conducted during a particular part of the summer, such as early August, live fuels could be sampled in late July and early August of the previous summer to get an estimate of their possible moisture levels and thereby their influence on fire behavior at that time of year.

If the fire must be conducted during a particular part of the season, fuels need be sampled only before and during that period until prescribed fuel moisture conditions are met. If the prescription requires a specific set of weather and fuel moisture conditions, then sampling should begin a few weeks before the prescribed fire is likely to be burned. The frequency of sampling should be increased from weekly early in the season to daily as the proposed date of the fire approaches, or when the set of required moisture conditions is met and it is time to burn.

Fuels can be sampled at intervals throughout the day to determine when conditions are nearest to those called for in the prescription. If the fire will be staged at a certain time of the day, such as late afternoon, the fuel moisture samples should be collected during that period daily before the fire. Evening hours in midsummer and late summer when temperatures and humidities often change rapidly can be critical.

Where Samples Should Be Collected

The number of samples collected is less important than their quality and how well they represent the sampled area. Regardless of the fuels to be sampled, they should span the range of conditions, elevations, positions, and situations each fuel experiences on the area expected to burn. The samples should be collected within the area to be burned. A line-transect across representative topographic and microclimatic variations within the area to be burned is often a good way to get representative samples. For example, if the sampling area is on a slope, the samples should usually be taken at points distributed between the highest and lowest elevations within the burn area. Similarly, samples should be collected from all directional aspects within the area. Notably wet and dry locations should be sampled, along with the areas between them. The same applies to shaded and exposed spots, greater and lesser concentrations and depths of fuel, older and younger stands, and any other within-plot variations that might influence fuel moisture content.

If the purpose of the sampling is part of the preparations for a prescribed fire and if the fuels surrounding the fire area are notably different from those within it, the surrounding fuels should also be sampled. Differences in anticipated fire behavior within and outside the intended fire area help to determine the needed contingency suppression forces in case the fire escapes.

The Number of Samples To Collect

Samples cost money, but so do errors in estimating how a fire will behave. The variability of the moisture content of a particular fuel across a burn unit at any given moment, along with the required precision, combine to determine how many samples are needed. When the fire is to be a prescribed fire, the procedure is fairly straightforward. Since sampling will be done regularly before the burn date, prefire samples can be used to determine how many samples must be collected to guarantee the needed precision. Some basic statistics may help. The sampler must decide from prescription guidelines or calculation models and an acceptable risk how accurate the estimate of fuel moisture content must be. The tolerable range in the estimate of fuel moisture in a specific situation is called the acceptable error (*E*).

For example, for small diameter dead fuels that usually carry a fire, the sampler might wish to have an estimate within 1 percent of the true value and to be 90 percent sure the estimate is within that range. On the other hand, for live needles it may be adequate to be only 80 percent certain that the sampled moisture content falls within 20 percent of the true average value for the burn area. The sampling densities required for the two fuels are likely to be quite different.

In any event, an estimate of the variation across the burn area is needed. Help can be found in the prefire samples as they are regularly collected and processed. You can use these samples with the procedure that follows.

The standard deviation is calculated:[2]

$$s = \sqrt{\frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n-1}} \; ; \qquad (1)$$

where:

s = standard deviation;
x = moisture content of each sample;
n = number of samples collected;
Σ = summation.

The acceptable error is E and the required number of samples m. The derivation for the equation for m is in appendix A. The result is:

$$m = \frac{(t^2 s^2)}{E^2} \; ; \qquad (2)$$

where t is a common statistic that depends on the number of samples and the confidence level you will accept. A table of t values can be found in statistics texts or manuals (for example, Freese 1967).

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[2] Many low-cost, hand-held calculators are programmed to calculate the standard deviation and many of the statistics mentioned.

As a hypothetical example, suppose the acceptable precision for small diameter dead fuel is ±1 percent of true value, with a 90-percent assurance that a set of samples will have an average value within that range. The values for a previously collected set of samples of moisture content are those under x.

	x	x^2
	7	49
	9	81
	8	64
	7	49
	6	36
	8	64
	9	81
	10	100
	9	81
	8	64
	7	49
	6	36
Total	94	754

Each sample value is multiplied by itself and listed as x^2. There are 12 values of x, so $n = 12$. One can now determine how many samples to take to be 90 percent sure the result is within ±1 percent of the true value of fuel moisture content.

First, the standard deviation is calculated by the use of equation (1):

$$s = \sqrt{\frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n-1}}\,; \tag{1}$$

$$s = \sqrt{\frac{754 - \frac{(94)^2}{12}}{12-1}} \doteq 1.267.$$

E is ±1 percent. The only remaining value needed to solve for m in equation (2) is a value for t. Two things are needed to enter a t table. They are degrees of freedom (df) and a probability.

Degrees of freedom equals the number in the sample minus one. Therefore:

$df = 12 - 1 = 11.$

Probability is:

$$\frac{(100 - \text{desired confidence level})}{100} = \frac{(100-90)}{100} = \frac{10}{100} = 0.1.$$

In a t table, at the intersection of a df of 11 and a probability of 0.10 is found the value $t = 1.796$.

From equation (2), the necessary number of samples is:

$$m = \frac{t^2 s^2}{E^2} = \frac{(1.796)^2\ (1.267)^2}{(1)^2}\ ;$$

$m = 5.178$.

To be sure enough samples are taken, round the value of m to the next highest integer, or 6. Six samples of this particular fuel from the burn area are needed to be 90 percent sure that the average value of the moisture content will be within 1 percent of the true value.

The worksheets shown in appendix B have been designed as an aid for determining how many samples should be taken to achieve a certain precision with a chosen level of confidence. Before using such a worksheet, the user needs:

1. To know how much error can be tolerated for the job.
2. To know how sure he or she wants to be that the results will be within that error limit.
3. To have a set of pilot data (samples previously collected).

The example just worked out is shown on the worksheets in appendix B. Blank worksheets are in appendix C.

When no pilot data are available, judgment and experience must replace reliable calculations to determine how many samples to collect. When the fuels are uniform and homogeneous on a smooth slope on one aspect, as few as three samples of each fuel may be enough for 100 acres. Where fuels and site conditions vary considerably within the area to be burned, as many as 20 samples may be required for a unit that size. Experience in Alaska black spruce forests comprised of fairly homogeneous stands indicates that 10 samples carefully collected to represent all significantly varying conditions on a site up to 100 acres in size are enough to give an average value, with an error acceptably small enough for even the most meticulous prescribed fire treatment. This, however, is only cursory advice, and each user should keep a record of all samples collected in a given fuel type to serve as a guide for future sampling. The procedure just described can be used to determine the proper sampling densities in a new fuel type.

Collecting and Processing the Samples

Equipment Needed for Fuel Sampling

Containers.—Containers for fuel moisture samples should have tight-fitting lids and be rustproof, permanently numbered, and of a material that can be put directly into a drying oven. From our experience, the best containers are drawn aluminum soil sample cans. The tight-fitting lids limit evaporation, and they do not oxidize, which is important in preventing errors caused by reduction in the weight of cans. Cans 2½ inches in diameter and 1¾ inches high work well for all fuels except large-leaved shrubs, such as prickly rose (*Rosa acicularis* Lindl.) and highbush cranberry (*Viburnum edule* (Michx.) Raf.). For these species, a can 3¼ inches in diameter by 2 inches high is better. Glass jars are too heavy and fragile. Paint cans eventually lose their tight-fitting seal and are too large for most sampling purposes. Plastic containers tolerant of high temperatures are suitable in some cases.

Both the lids and the sides of containers should be permanently identified with a number. Each empty container and lid should be weighed together, to the nearest 0.1 gram (tare weight[3]), and the identification number and weight permanently recorded in your files.

Sample carrying case.—A carrying case (fig. 1) for sample cans should be constructed from plywood or other sturdy material. The case should hold the samples securely, have a hasp or other type of latch and a carrying handle, and provide a place to put field data sheets (an envelope taped to the inside of the case works well). The size of the case depends on the dimensions of the sample cans and the number of samples to be collected each time, but the case should be easy to carry through vegetation and compact enough to fit in vehicles and aircraft.

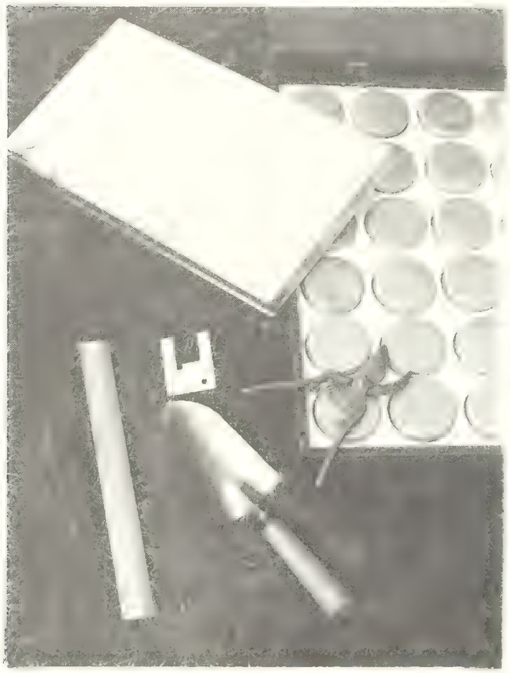

Figure 1.—A carrying case for sample cans should hold the samples securely. A covered notebook, clippers, trowel, ruler, and fuel gage are standard sampling equipment.

Clippers.—Good quality pruning shears (fig. 1) with two curved sharp blades are most effective for clipping fuels. At least two pair should be used: one for dead woody fuels and the other for live fuels. Sharpening may be necessary during the field season.

Garden trowel.—A trowel (fig. 1) with a heavy shank and a sharp blade is used for duff and soil moisture sampling.

Fuel gage.—Cut from rolled steel or heavy aluminum, a fuel gage (fig. 1) is used to check the diameter of a particle of dead woody fuel.

Ruler.—A ruler that resists breakage and repels water and is long enough to measure duff depths should be included.

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[3] The weight of the empty clean container.

Tape.—One-half-inch-wide drafting tape is the best tape for sealing sampling cans because it can be readily removed from the can. Masking tape can be used, but it frequently leaves a residue that is hard to remove, particularly if the exterior of the can becomes damp or hot. Wide rubber bands or cross sections of motorcycle tire inner tubes have also been used successfully and are reusable.

Clipboard.—A covered clipboard for holding the data sheets, field notes, or this sampling guide is a great aid in the field.

Gloves.—Heat-resistant gloves with a fair amount of flexibility are needed to remove heated samples from the drying oven.

Data sheets.—All data sheets should be designed specifically for a particular sampling job. Two sheets are required: one for field use (see appendix D) and one for fuel moisture calculations in the laboratory (see appendix E). The field data sheets are used to list the locations, dates, sampling times, name of person doing the sampling, all fuels to be collected, the number of each sample can, and any observations or comments. Because the field sheets often become smudged and rumpled, the laboratory sheets should be used for recording drying times and calculations of sample weights and moisture content of the fuel. Both sheets are retained for transferring and documenting data.

Drying oven.—An electric oven specifically designed for drying samples should be obtained. The best type is a mechanical convection oven with a built-in fan to circulate the heated air and ventilate the oven. Fuels dry more uniformly and rapidly than in a gravity convection oven. This agrees with guidance given by Countryman and Dean (1979). The oven must be able to maintain a regulated temperature of 100 °C and have adequate volume to allow air to circulate freely around all samples. Depending on the number of samples to be processed at one time and the size of the oven, an extra shelf and mounting brackets can be purchased to increase the capacity of the oven without impairing its performance.

Scale.—A scale is needed for weighing the samples. The same scale should be used both times the sample is weighed. A top loading, beam or torsion balance scale, capable of accurately measuring to the nearest 0.1 gram, is adequate for weighing most fuel samples. If an electronic balance is available, the job can be done more accurately and quickly. The cost, however, is justified only if many samples will be processed over a long period or if greater precision is necessary.

The scale should be checked for accuracy before the field season and regularly during use. The calibration of beam or torsion balances must be performed according to the manufacturer's directions, using the calibration weights provided. Almost without exception, precision electronic scales must be adjusted by the manufacturer.

The scale must be placed on a firm, level surface such as a heavy table or counter top. The area must be free from drafts that cause movement of the scale mechanism and lead to inaccurate readings.

Collecting the Sample

On arrival at the sampling site, place the sample case in a shady spot and prepare the field data sheet. Record the site number, date, time, name of observer, and the can number for each fuel sample to be collected.

Do not collect live fuels if waterdrops are present on leaves or stems. Such free surface water will cause large errors in calculated values of moisture content. Shaking the leaves to remove excess water is not adequate because enough free water can remain to bias the sample. If rain prevents collection of certain samples, write rain in the space where the can number for these samples would be recorded. If no rain has fallen for several hours, the moisture may have evaporated from some of the plants, and sampling can proceed. Dead fuel samples and lichens and mosses may be collected if recent precipitation has occurred, but the presence of any free surface water should be recorded on the data sheet. Duff and organic layer samples may be collected even if rain is falling, but great care must be taken to prevent raindrops from getting into the sample can.

Materials such as mosses, lichens, shrubs, herbaceous plants, grasses, and grass and leaf litter become fairly stiff as they dry, and they may spring from their cans while in the drying oven. This makes the lid difficult to replace, and some of the sample may fall out. For this reason, pack mosses, lichens, leaf litter, organic layer material, and duff loosely in the sample cans. Never compress them to get additional material into the can. It is better to fill several cans than to force too much into one can. Collect an adequate amount of sample material, filling the can about three-fourths full.

Cut the stems of each shrub and herbaceous plant into small pieces as they are dropped into the can. Clip all of the sample again after it is in the can. Cutting the plants into smaller pieces also allows a greater amount of material to fit into a can. Clip grass and sedge leaves from various plants, holding the entire sample in one hand. Then cut all leaves together into short sections as they are dropped into the can (fig. 2).

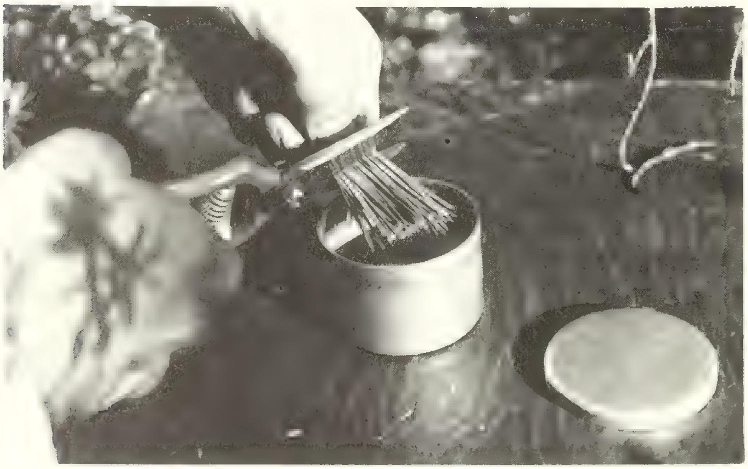

Figure 2.—While holding the grass and sedge sample material in one hand, clip all blades into a size that will fit into the can without bending them.

Stack the large leaves from such shrubs as rose or highbush cranberry in one hand and cut them into halves, then quarters or smaller sections as shown in figure 3. Do not **drop** the cut sections of leaves into the can—place each stack of leaves on its side in the can. This is important because the leaves curl as they dry, greatly increasing both the space they occupy and the chance of losing part of the sample in the oven.

As you move about the site and collect material, replace the lid on the can to cover materials already collected. When the can is filled, immediately replace the lid tightly and seal it by encircling the lid with **one** layer of drafting tape (fig. 4). It is easier to remove the tape if a small length of the end is folded onto itself, to form a tab. Be sure no dirt or debris clings to the outside of the sample container. Any comments or observations about plant phenology (as discussed later) should be recorded on the field data sheet.

Arrange the cans in numerical order in the carrying case, along with the field data sheets. Keep the samples cool and dry until they are weighed. If the collected samples receive even moderate heat, some moisture will evaporate, possibly escaping the can, or else remain as vapor and be lost when the sample is opened, yielding an error. Further, decomposition could begin, again causing a loss in weight of the sample and an error. Refrigerate the samples if they cannot be weighed the same day as collected.

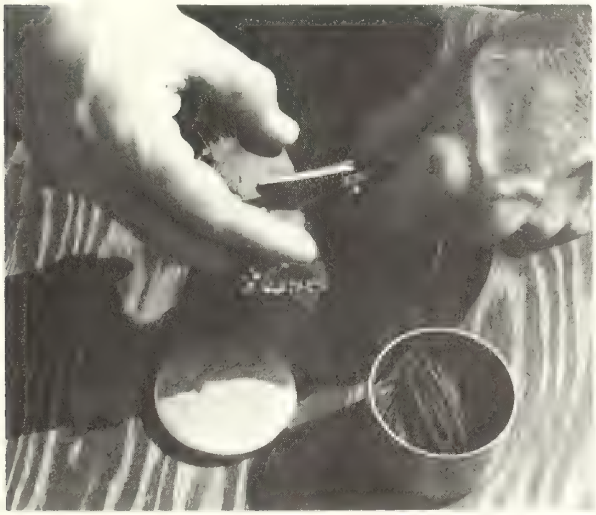

Figure 3.—Cut a stack of large leaves into smaller segments and carefully fit them into the sample can.

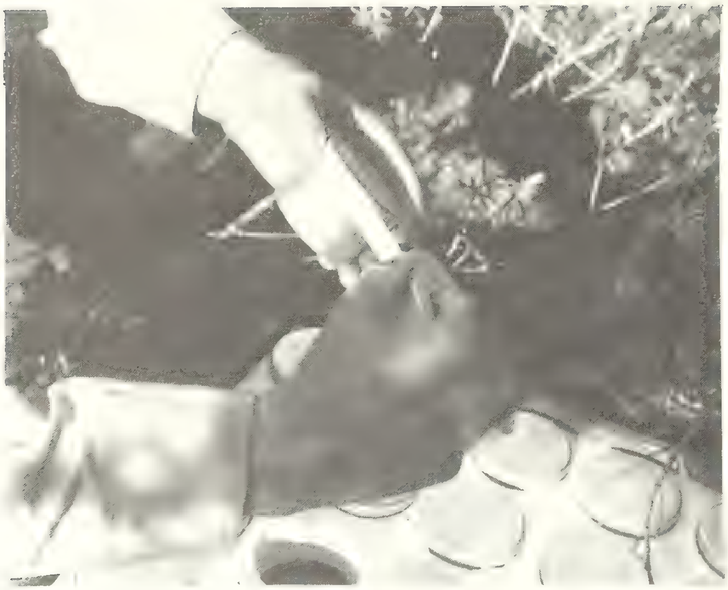

Figure 4.—Use **one** layer of drafting tape to seal the sampling can. Be sure to tape around the entire lid.

Weighing the Sample

Preheat the drying oven to 100 °C. Transfer the information from the field data sheet to the laboratory calculation sheet. Remove the tape from the can lid. Make sure no tape or other debris is stuck to the outside of the can. Adjust the scale to zero. Place a can on the center of the scale platform. Read the scale and record it as the "wet" weight on the laboratory calculation sheet. Check to see that the identification and contents of the can match those recorded on the field and laboratory sheets. Remove the can from the scale and replace the lid. If any sample material falls out during weighing or when placing it in the oven, weigh the sample again.

Repeat this procedure until all samples are weighed. Be sure to set the scale to zero before each sample is weighed, because the adjustment can be changed by minor vibrations and movement of the scale, causing errors.

Remove the lid and place it under the can as you put the sample in the drying oven. Arrange the cans in numerical order, with numbers facing toward you. Space the samples evenly in the oven so that air circulates freely around every can. If few samples are being dried, center them on the middle rack of the oven. Record the date and time that the samples were put into the oven.

Drying the Sample

Dry the sample for 24 hours at 100 °C, or 18 hours at 100 °C if only live fuels are being processed. Large samples of very wet duff should dry 48 hours. **Do not** put additional samples into the oven while drying a set of samples. If you do, the original samples will absorb moisture from the new samples and must then be dried an additional 24 hours.

At the end of the required drying time, take the samples from the oven and quickly replace the lid tightly as each can is removed. This prevents the absorption of moisture from the air. **Do not** leave the oven door open. It should be opened only long enough to remove a few samples, because moisture from the room will enter the oven and will be quickly absorbed by the dried samples inside. Enough moisture could easily be added to the samples to cause a significant error. If any sample material falls from a can during the drying process, throw the sample away unless you know which can it fell from and you can replace all of it in the right can.

Allow the covered cans to cool to room temperature before weighing them. Hot air in the can causes buoyancy and may result in a weighing error, particularly if the samples are very light. If you cannot wait for the samples to cool, remove the lid just before each sample is weighed, place the lid beneath the can and then put the sample on the scale. Weigh the sample quickly and record its (dry) weight. If the sample was cooled to room temperature before it was weighed, it can be weighed with the lid on. In either case, check the can number and its contents before you record the dry weight on the laboratory sheet. Check the scale for a zero weight setting before weighing the next sample.

After each dried sample is weighed, replace the lid tightly on the can and save the sample until the fuel moisture content is calculated. If an obvious error appears in the calculation, the sample can be weighed again and the source of the error may be found. Once fuel moisture calculations have been made, discard the sample and clean the cans for reuse. Remove **all** sample and tape residue from the cans. Wiping with a clean rag is sometimes enough to clean the insides of the cans, but they must be washed and scrubbed frequently. Containers must be free of soap residue and completely dry before the lids are replaced and the cans are stored for future use. Air drying is more effective than wiping the cans dry.

Calculating Moisture Content

The formula for calculating percent moisture content is:

$$\frac{\text{Weight of water in sample}}{\text{dry weight of sample}}\ (100) = \text{percent moisture content.}$$

This is equal to:

$$\frac{\text{Wet weight of sample} - \text{dry weight of sample}}{\text{dry weight of sample}}\ (100) = \text{percent moisture content.}$$

This is most easily done by the following formula:

$$\frac{\text{Wet sample weight} - \text{dry sample weight}}{\text{dry sample weight} - \text{container tare weight}}\ (100) = \text{percent moisture content.}$$

Here is an example:

Wet sample weight = 48.2 grams. Dry sample weight = 46.9 grams. Container tare weight = 38.1 grams. By the formula above:

$$\frac{(48.2 - 46.9)}{(46.9 - 38.1)}\ (100) = \frac{1.3}{8.8}\ (100) = 0.1477\ (100) = 14.77 \text{ percent}$$

or: $\approx$ 14.8 percent moisture content.

If the averages of many similar samples are to be calculated, one decimal place should be kept, to maintain precision, rather than rounding to the nearest whole number.

If a programable calculator capable of storing information in three registers is available, the writing of a program for this procedure will greatly increase the speed and accuracy of the calculations. Whether the computations are done by hand or with a calculator, **repeat** the calculations to be sure they are correct. A list of the most common sources of error while processing samples is included in a separate section at the end of the paper.

Collecting Dead Fuels

Down and Dead Woody Fuels

Samples of 0- to 1/4-inch- and 1/4- to 1-inch-diameter down and dead woody fuels should be taken from several branches resting on the ground. Do not collect the entire sample from one location or from a single branch. Collect twigs of as many sizes as possible within the size class. All samples must be collected from dead wood that is detached from its growth point. Do not collect parts buried in the litter, duff, or moss. Do not collect dead branches attached to the bases of live trees or detached branches inclined more than 45° from the horizontal. Do not sample from trees or branches that have recently fallen. Cut several 1- to 1½-inch-long sections from each 0- to 1/4-inch diameter down, dead branch. Collect only one piece from each 1/4- to 1-inch down, dead branch (fig. 5). Remove all lichen or other debris and very loose pieces of bark from the samples. The wood collected does not have to be completely sound but should not be decayed to the point of being easily rendered into powder or splinters when rubbed between your fingers. Some splitting caused by drying is acceptable. Wood in various stages of decay should be collected in proportion to its presence on the site, as long as the rules just stated are followed.

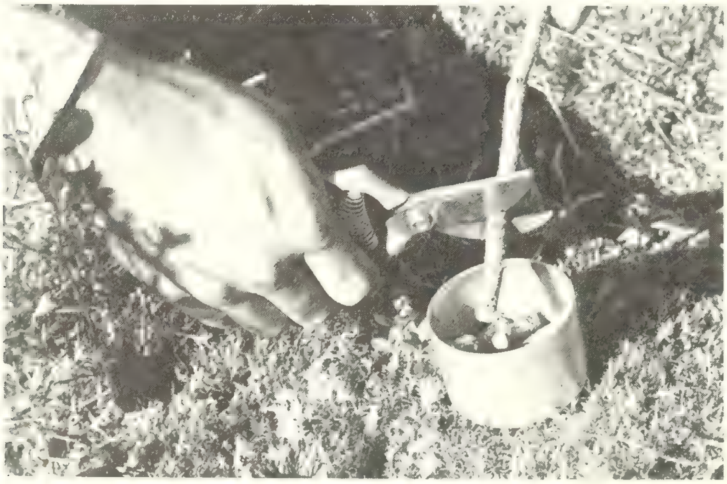

Figure 5.—When collecting 1/4- to 1-inch down and dead woody fuels, cut one piece about 1 to 1½ inches long from each dead branch on the forest floor.

Duff

Moisture content of the duff has important influences on the depth of burning of the forest floor. It must be sampled carefully and selectively if the impacts and results of the fire are to be predicted well. For duff samples, the depth is very important and should be measured, not estimated (fig. 6), with the base of the moss and lichen or litter layer as a reference point. It may be necessary to collect several duff samples at one spot, each at a distinct depth, to accurately represent moisture conditions; the upper layers of duff wet and dry at a faster rate than deeper, more compact duff layers and may have a significantly different moisture content. Select spots that are representative of the area. Duff samples should not be taken from elevated mounds of moss or thick patches of lichens unless they are representative of the area.

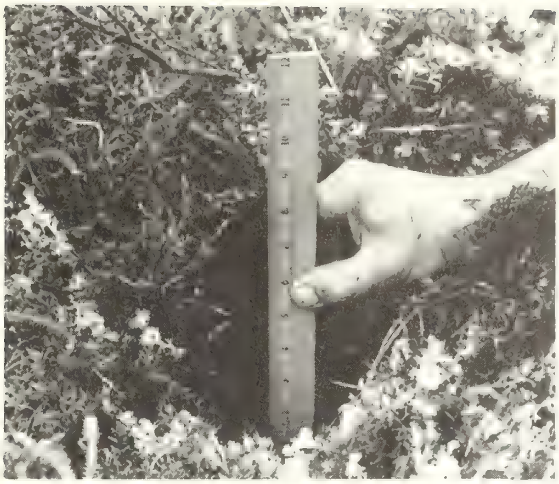

Figure 6.—When collecting duff samples, measure the depth below the bottom of the moss and lichen layer; do not estimate it.

The duff layer can be differentiated from the layer of mosses and lichens or leaf litter above it because the plant material in the duff layer is so decomposed that the plant species are not readily identified. Another common characteristic of the duff layer is the presence of a dense network of fungal hyphae, very fine hairlike strands, usually white or very light gray.

Remove all live plant stems, roots, rhizomes, other parts of living plants, and animal droppings from the sample. Be especially careful to avoid including mineral soil or stones in the duff sample, but do not let this caution prevent you from sampling duff near its maximum depth. The presence of mineral soil can often be detected by rubbing questionable soil between your fingers. Soil particles are fine enough (in the silty soils of interior Alaska) to fill the indentations in your fingertips. When mineral soil is found in a sample, discard it, go to another location, and start sampling again.

Mineral Soil

It may be necessary to collect soil moisture samples to predict the survival, after a fire, of roots and rhizomes distributed in upper soil layers. Procedures for sampling mineral soil are similar to those for collecting duff. Collect samples from representative spots, and measure the depth below the surface of the mineral soil. The samples should contain no living or decomposing plant material or stones.

Hardwood Leaf Litter

Gather leaf litter from both sunny and shady spots within a stand. If the canopy is uniform, visit only a few locations. Collect only uncompacted dry leaves. Usually the upper one-half inch of leaf litter has whole, undecomposed leaves suitable for collection. In stands with a sparse canopy cover or thick stands of grass, collect leaf litter samples both from exposed areas and from spots where the grass cover is meager.

Dead Grasses and Other Grasslike Plants

Collect the sample from 15 to 20 plants. Clip dead blades from all vertical portions of tall grasses, such as bluejoint (*Calamagrostis canadensis* (Michx.) Beauv.), and from tops and sides of cottongrass (*Eriophorum* spp.) tussocks. Collect blades that are brown or tan, not gray or decomposed. If rain has recently fallen, collect only blades of grass that are in a fluffy, loosely compacted arrangement and have no drops of water on them. Collect the entire sample and then clip it into short pieces as you place it into the sample can.

Collecting Live Fuels

Most major changes in the moisture content of live plants are associated with physiological events in their annual life cycles. Noting the occurrence of these events each time a live fuel sample is collected gives you useful information for describing their flammability. The kinds of events that should be recorded include:

Shrubs:
  End of dormancy—buds bursting; beginning of shoot growth.
  New shoot growth complete—new stems darkening; new terminal bud apparent.
  Autumn leaf color.
  Leaves falling off twigs.
  All leaves gone—winter dormancy.

Forbs and grasses:
  Sprouting of plants.
  Plants attaining full size; no new growth apparent.
  Presence of ripe berries or seed heads.
  Curing of foliage.
  Cured foliage.

Conifers:
  Bud break—beginning of new needle and stem growth.
  Active shoot and needle growth.
  Ending of growth period—terminal bud developing at end of the current year's shoot.
  Terminal bud and new stems brown and hardened for winter.

Mosses and Lichens

The procedure for collecting mosses and lichens requires some subjective judgment. Carefully gather and inspect some of the plants before collecting any samples. A close look with a hand lens or binocular microscope will make these sampling guidelines easier to follow.

Feathermosses and associated ground lichens can be sampled separately or included as part of a composite sample containing each in proportion to its presence on the site. Gather mosses and lichens from exposed locations on the forest floor, not beneath tree crowns or dense shrubs.

Many species of mosses and lichens grow in the interior of Alaska, but only feathermosses and fruticose lichens should be collected. Feathermosses have a fairly upright form, many small branches, and a fluffy, feathery appearance (fig. 7). A mature stand of feathermosses usually forms a loose, springy, interwoven mat on the forest floor. Fruticose lichens have upright, thin stalks, frequently with many finely divided branches (fig. 8). Fruticose lichens may form pure lichen mats or may be intermixed with feathermosses on a site. There is a common group of lichens with a flat, leaflike form that grow on top of the moss layer. Do not include them in a sample.

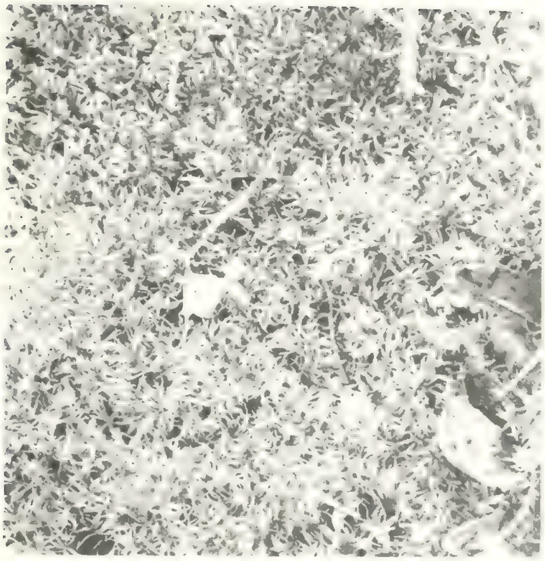

Figure 7.—*Hylocomium splendens* is a commonly occurring species of feathermoss. Be sure to remove dead leaves, grasses, and twigs from the sample

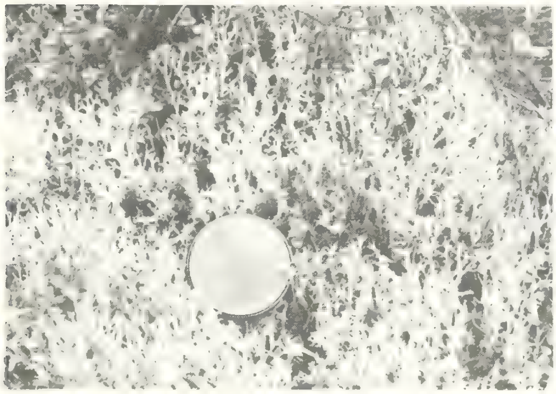

Figure 8.—Several species of commonly occurring fruticose lichens.

Lichens and mosses grow continuously from the same stem. Each year new material forms at the top, and part of the base dies. A thick mat of mosses and lichens forms, with a thin layer of live mosses and lichens on top of and connected to a thick layer of dead mosses and lichens. If a deep moss and lichen layer is present, the upper living parts of the mosses and lichens may have a distinctly different moisture content than the lower dead parts; the upper part of the moss and lichen layer is much fluffier and receives more direct exposure to the elements than the lower part of the layer. For this reason, collect separate samples of living lichens and mosses in the upper part of the layer and the dead lichens and mosses beneath them.

Here are some guidelines to help differentiate between living and dead segments of these plants. The living parts of the moss plants are pale green. The dead part is pale brown and may be slightly decomposed, but not so much so that its species characteristics are lost. Farther down the stem, decomposition removes the fine branches of the moss plant, leaving only a dark brown stalk with a few branch remnants.

Differences in color between live and dead lichens are usually subtle, although the dead base of one common species group turns orange. Some dead lichen parts become gray. Other lichens become very porous. Many of the finely divided branches of dead lichens decompose and break off. As decomposition advances, lichens become dark gray or black and are very mushy when wet. These decayed, dark lichens and the dark brown mosses are considered part of the duff layer and should not be included in the moss and lichen sample.

To collect the sample, grasp a few mosses and/or lichens and gently pull them from the moss and lichen layer. Clip off the highly decomposed dark brown moss (fig. 9) and the dark or obviously decomposed lichens (fig. 10) at the base of the layer. Pinch off the plants at the boundary between the upper and lower layer. Then separate the living plants from the dead ones by pulling or clipping them apart. Repeat this process at several locations until the two sample cans are full.

Remove all twigs, undecomposed leaves, live and dead club mosses, and plant stems and rhizomes. Note on the field data sheet if free water is present on the mosses and lichens.

Do not mix sphagnum moss (fig. 11) with feathermosses in your sample, even though they grow together on the site. Sphagnum has a noted ability to retain free water, and it rarely burns except in special cases such as when cured logging debris on top of it is burned.

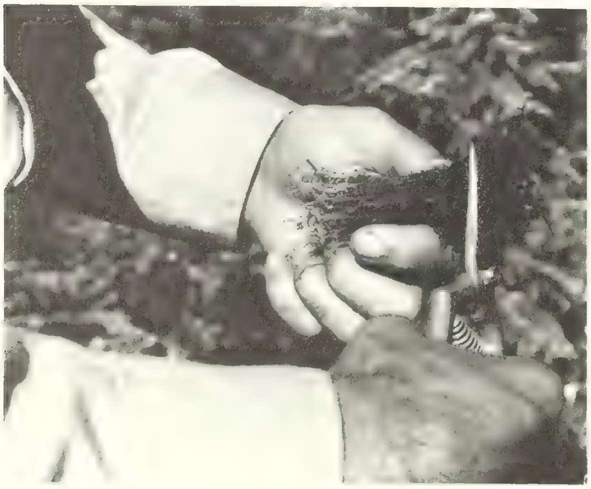

Figure 9.—Use clippers to remove the highly decomposed dark brown moss from the sampled material.

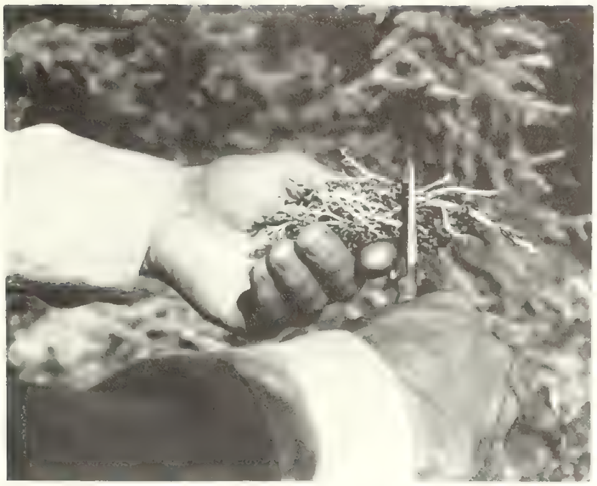

Figure 10.—Clip off and discard the decomposed base of the lichens.

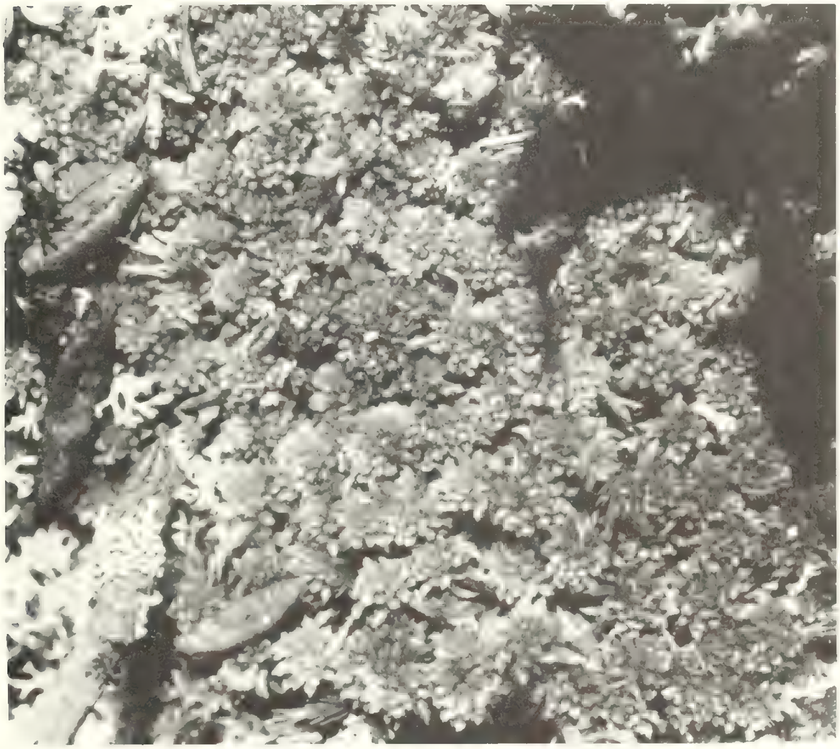

Figure 11.—Because sphagnum moss has a very dense growth form that allows it to retain free water, it rarely dries enough to burn and therefore should not be included in the feathermoss and lichen sample.

Shrubs

Shrubs are classified into three groups according to their height: large shrubs 6 to 20 feet tall; medium shrubs 2 to 6 feet tall; and small or low shrubs up to 2 feet (Viereck and Little 1972). Most of the mass of large shrubs is above the carrier fuel layer and has little influence on the behavior or characteristics of fires. Consequently, tall shrubs are seldom sampled; however, fire spread can be influenced by the moisture content of shrubs of low and medium height. Because medium shrubs have much higher levels of moisture content than low shrubs (data on file at the Institute of Northern Forestry, Fairbanks), you should sample the two groups separately. Evergreen shrubs have a seasonal moisture cycle that is very different from that of deciduous shrubs, so a separate sample is needed.

Make a composite sample of all the species within each shrub group (that is—medium or low, evergreen or deciduous), sampling each species in proportion to its presence on the site. If individual plants are very large, with large leaves, a separate collection for each species should be made unless a very large sample can is used.

When sampling shrubs, collect only the new, small diameter stems and their associated leaves. Many shrubs tend to produce most of their growth on upper branches. Some twigs do not produce new stems. The amount of material collected from each shrub species should be proportional to its presence on the site. Only one section of stem should be clipped from any plant. Collect samples from both exposed and shaded locations. Eliminate all dead twigs or twigs with diseased or insect-infested leaves. Do not include flower buds, flowers, seed pods, or berries in any stage of development.

Here are some guidelines for collecting samples of some of the major shrub species of Alaska:

Highbush cranberry.—New leaves grow on the new shoots as well as on stem sections formed during recent years. Collect new stems and those 1 and 2 years old, along with their leaves. Each year's growth can be readily identified by a bud scar that encircles the stem. Include the long shoots at the top of the plant and the very short shoots on the sides of stems that often bear only two leaves.

Prickly rose.—All of the leaves and flowers on this species of rose are located on the new stems produced each spring. Do not collect old, stiff stems. New stems are pale green and can be readily differentiated from older stems for most of the summer. The new stems turn darker as autumn approaches and begin to resemble older ones. Clip entire new stems with their associated leaves from the plant at the point where new growth and previous growth meet.

Buffaloberry (*Shepherdia canadensis* (L.) Nutt.).—Collect foliage and twigs produced during the current year and the previous 2 years. No bud scars separate each year's growth, but distinct differences in stem diameter and color identify the age of growth. Early in the season, new stems are very pale brown. The 2 older years' growth becomes increasingly darker in color and thicker in diameter. Tiny, star-shaped clusters of hairs are much more apparent on the new growth. Later in summer, the stems formed 2 years ago will turn gray and be difficult to distinguish from older growth.

Blueberry (*Vaccinium uliginosum* L. subsp. *alpinum* (Bigel.) Hult.).—The leaves of blueberry are found only on new stems. Collect this material and the stem segments produced the previous season (fig. 12). Stem sections 2 years old and older are much darker and have shaggier bark than younger stems. New stem growth is pale green, becoming darker green as the growing season passes. A bud scar separates each year's growth but is sometimes difficult to see. The tip of a stem frequently dies during winter, and new growth develops from the uppermost lateral bud. These dead stem tips may help you distinguish between last year's growth and older stem growth. Green berries can be easily overlooked among the leaves but must be found and removed, as well as all flowers and ripe berries.

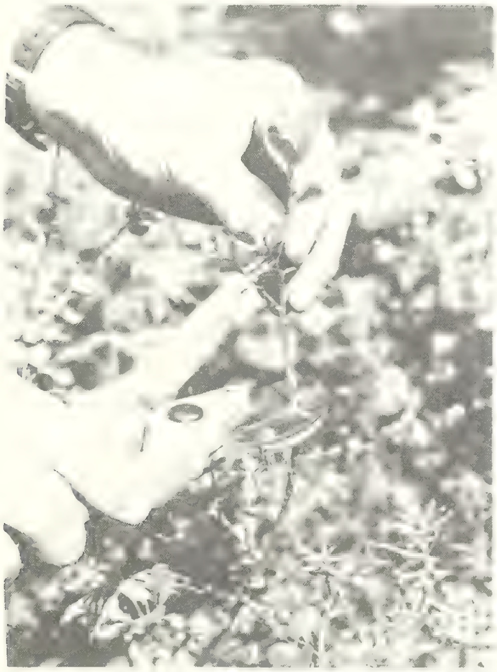

Figure 12.—Collect the blueberry stems bearing leaves and the segment of stem produced the previous year.

Shrub birch (*Betula glandulosa* Michx.).—Sample stem and leaf material produced this year and last year. New stems of shrub birch are very pale brown early in the season, and they slowly darken to gray brown during the summer. After the 2d year of growth, twigs become gray, and the glandular dots on the stem surface become much less obvious. A bud scar encircling the stem marks the end of each year's growth.

Spiraea (*Spiraea beauverdiana* Schneid.).—Spiraea leaves occur only on the current year's growth. Include only that material in the sample. Do not collect older stems. Cut the stem where it is connected to the previous year's growth, which is marked by small, clasping leaves. Spiraea has two growth forms. One has very thin, multibranched twigs; a less common type has fairly thick, single stems. The latter are basal sprouts which develop one year and branch during subsequent years. Collect both forms in proportion to their presence on the site. The single stem form is very succulent early in the growing season, so do not include too high a proportion of this material or it will bias the sample toward a moisture content that is too high.

Labrador tea (*Ledum palustre* L. subsp. *decumbens* (Ait.) Hult. and *Ledum palustre* L. subsp. *groenlandicum* (Oeder) Hult.).—Labrador tea is an evergreen shrub that retains its leaves for two growing seasons, rarely three. Leaves formed one year usually begin to change color in July of the next year. Collect the current and previous years' stem growth and any attached leaves (fig. 13). Do not include stem sections and leaves that are more than 2 years old. Age can be determined from bud scars separating each year's growth.

Labrador tea has two kinds of stems; those that only produce leaves (fig. 14) and those that also flower. The flower bud is pale brown, covered with scalelike, overlapping leaves, and is notably larger than the vegetative bud. Several lateral, leafy branches sometimes form on the flowering stems after the seed development process is nearly complete. Collect both leafy and flowering shoots, but remove all flower buds, flowers, seed capsules, and remnant seed stalks.

Mountain cranberry and lingonberry (*Vaccinium vitis-idaea* L. subsp. *minus* (Lodd) Hult.).—Mountain cranberry is a low-growing evergreen shrub that retains its leaves for several years. Some stems produce new shoots with leaves, others develop flowers, and some stems produce no new growth at all. Sample all three kinds of stems. Growth may begin several weeks later than for most other shrubs, and it is sometimes difficult to determine when new growth has occurred. New stems and leaves are pale green, and older stem material is yellow green or pale reddish brown. Clip the stem just above the moss layer and include the section of the stem with healthy leaves. Discard flowers and all green or ripe berries.

Bearberry (*Arctostaphylos uva-ursi* (L.) Spreng. var. *uva-ursi*).—Bearberry is an evergreen shrub with a growth form similar to mountain cranberry. Sample bearberry in the same manner, including only portions of stems bearing leaves and omitting flowers and berries. Include stems with older leaves showing signs of fall color but not sections of stems retaining gray leaves that died in previous years.

Crowberry (*Empetrum nigrum* L. subsp. *hermaphroditum* (Lange) Böcher).—Crowberry is another low-growing evergreen shrub that keeps its leaves for several growing seasons. Sample the younger stem sections with green leaves, along with older sections with leaves that have turned yellow during the current season. Include new stems in proportion to their occurrence, but remove all flowers or berries.

Herbaceous Vegetation

Some herbaceous plants sprout from roots, rhizomes, or overwintering basal leaves several weeks after the shrubs have leaves. Therefore, the mix of species of herbaceous plants collected may change markedly the first few weeks of the growing season.

Forbs.—Collect the entire plant of small, single-stemmed forbs, such as wintergreen (*Pyrola* spp.) or bunchberry (*Cornus canadensis* L.), by clipping the stem at ground level. If a species, such as lousewort (*Pedicularis* spp.), has multiple stems, cut one stem with leaves from each plant. Also, cut leaves or sections of leaves and stems from other plants that are common to the site but few in number. If a large volume of sample material is being collected, take the entire stem of a large plant like fireweed (*Epilobium angustifolium* L.). Remove and discard all flowers and fruits in any stage of development from all herbaceous plants.

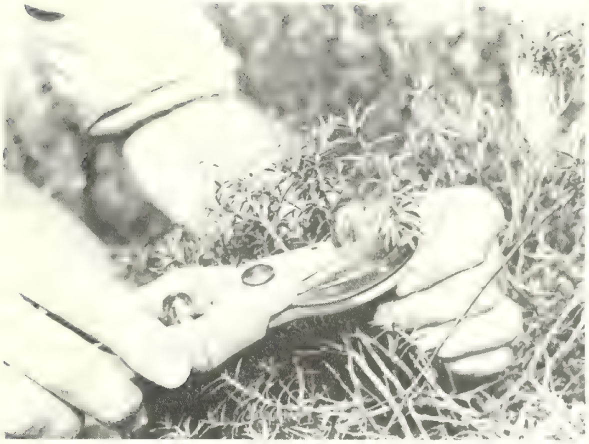

Figure 13.—When sampling Labrador tea, collect current and previous years' growth.

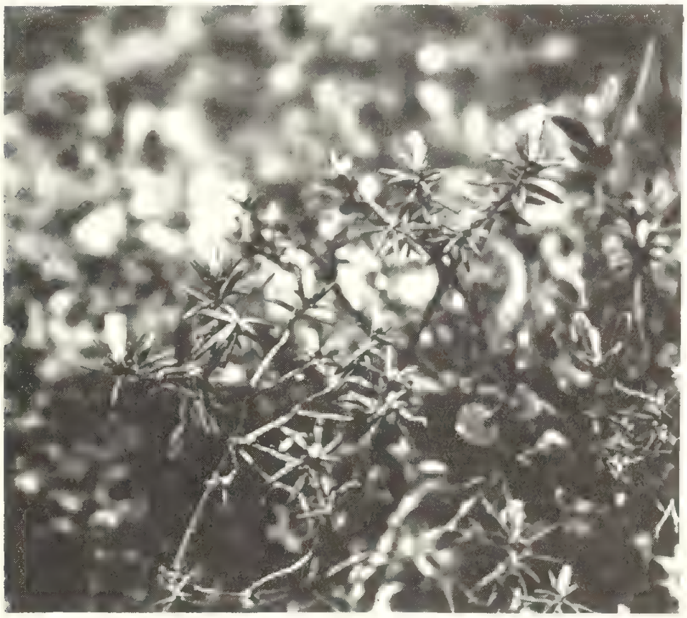

Figure 14.—New vegetative growth of Labrador tea begins in early June to mid-June, several weeks after deciduous shrubs break dormancy

Grasses and grasslike plants.—Collect only the leaves of grasses and sedges. Do not collect stems, seed heads, or succulent white or pale-green leaf bases. For tall grasses such as bluejoint, clip the leaves from all vertical portions of the plants, cutting the blades near their point of attachment to the stem. This is particularly important late in the season, because the lower blades begin to dry and cure earlier than those near the top of the plant.

For low-growing bunchgrasses, clip blades of different lengths from each clump; include only the leafy material and not the base of the leaves. Clip several blades from each clump of cottongrass (*Eriophorum vaginatum* L. subsp. *vaginatum*) or other sedges (usually *Carex* spp.). Because the leaves form continuously from the same growth point for several seasons, some live blades may have gray, shriveled material at their tips which died the previous year. Clip off and discard gray tips.

Individual blades die back during the summer, starting at the tip. Do not remove this reddish brown part of the leaf because it is part of the seasonal growth. Later in the season, when entire blades are cured, include them in the sample in proportion to their presence on the site. Do not collect seed heads.

Black Spruce Foliage

Gather needles and twigs from a minimum of eight 1-year-old black spruce trees in a stand (these methods are suitable for white spruce also). Collect needles from all sides and at various reachable heights of the tree. Needles formed in sequential years are separated by a bud scar located at the end of each year's growth. The needles attached just below the scar are inclined at a more acute angle to the branch than are the other needles (fig. 15). Also, the stem of 1-year-old growth is much lighter brown than the dark and slightly woody stem segment that grew the previous year. Collect the foliage by clipping the twig at the bud scar between the 1- and 2-year-old needles.

Remove and discard all this year's growth from each twig, including swollen buds. Buds begin to swell in late May. They are pale brown and turn pale green as the new needles increase in size. The new stems are also pale green, contrasting with the pale or medium brown of 1-year-old stems. New needles and stems become darker throughout the summer but remain readily distinguishable. Some branches do not produce new needles every year, so it is important to learn the characteristics of the new growth.

An easy way to remove buds and very young needle clusters is with the tip of a set of clippers. When new stems and needles are larger, you can grasp the cluster between two fingers and pull gently, separating it from the 1-year-old growth. You will see a pale brown concave scar if all new growth has been removed (fig. 16). If any new needles are still attached to the 1-year-old needles, the center of the new stem will be evident (fig. 17).

Be sure to remove all new buds and needles because their moisture content is many times higher than that of the 1-year-old needles. If they are included in the sample, the estimate of moisture content will be biased toward a much higher value.

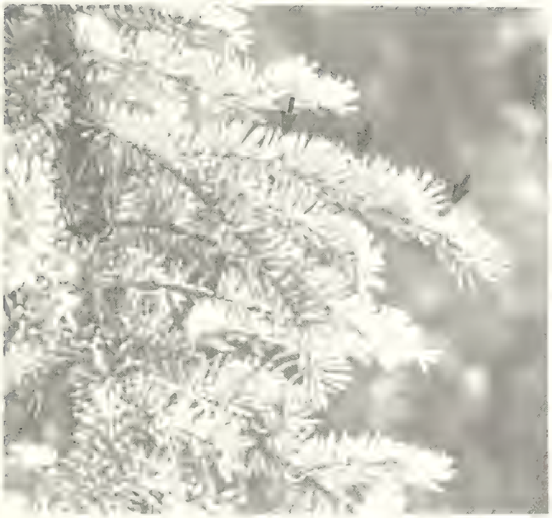

Figure 15.—The point on a black spruce twig that separates each year's growth is marked by several needles located just below a bud scar; these needles are inclined at a more acute angle to the twig than are adjacent needles.

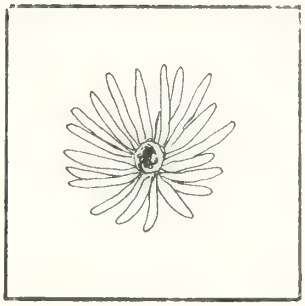

Figure 16.—If all new needle and stem growth is removed from the end of the branch, a brown concave scar, marking the end of the previous year's growth, should be evident.

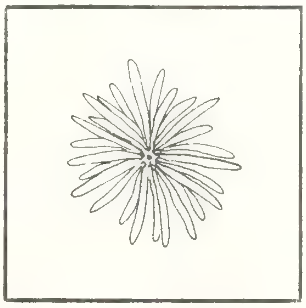

Figure 17.—If new growth is not completely separated from the 1-year-old stem and needles, the center of the new stem will be obvious. Carefully remove the new growth.

Common Sources of Errors

Field Errors

Some of the most common sources of error while collecting samples are:

1. The sample is placed in a can with a different number than is listed on the field data sheet. (The numerical sequence is frequently switched by accident when similar fuels, such as 0- to 1/4-inch and 1/4- to 1-inch down and dead wood are collected.)
2. An incorrect lid is placed on a can.
3. The can number is recorded incorrectly on the data sheet.
4. Drops of rain or other free water are allowed to fall into the can.
5. Sphagnum moss is included in the sample of lichens and feathermosses.
6. Stems, roots, and leaves of forbs or shrubs are included in the moss and lichen sample.
7. Soil, small rocks, animal droppings, and other material are included in duff samples.
8. The 1-year-old spruce needle sample is contaminated with the buds, needles, or stems of the current year's growth or that of previous years.
9. Berries are included in the sample.
10. An inadequate amount of material is collected. (Fill the can at least three-fourths full.)
11. Failure to collect material from several spots, plants, or limbs on a site. (Do not collect all of it from one spot.)

Laboratory Errors

Some common sources of error in the laboratory are:

1. Failure to check the can numbers against the sample contents as recorded on the laboratory calculation sheet (frequently initiated by switching the sequence of can numbers while in the field).
2. The material springs from the can while drying.
3. Failure to set the scale to zero before weighing a sample.
4. The can is not placed in the middle of the scale platform.
5. The scale is misread.
6. Errors are made during the entry of values into the calculator or while doing the calculations (possibly the greatest single source of error; **double-check!**).

Metric Equivalents

1 inch = 2.540 centimeters
1 pound = 453.6 grams
5/9 (°F−32) = °C

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Appendix A

Derivation for *m:* The Number of Samples To Collect

From the value for *s*, the standard deviation, a second statistic called the standard error ($S\bar{x}$) can be calculated:

$S\bar{x} - s/\sqrt{m}.$

This value can be used to describe a set of sampled values that has an average value ($\bar{x}$) and some distribution of values around that average. The concept is expressed simply by:

(The average of the sample) ± (standard error) (t) $= x \pm (S_x)\ (t) = x \pm E;$

where t is a common value that depends on the number of samples (m) and the confidence level you will accept. Note that the acceptable error (E) is

equal to ($S\bar{x}$) (t).

$E = (S\bar{x})(t),$

but $S\bar{x} = s/\sqrt{m},$

so $E = (s)\ (t)/\sqrt{m};$

solving for m:

$m = (t^2 s^2)/E^2.$

Appendix B

Sample Density Worksheet Example

I. Previous data (fuel, 0- to 1/4-inch down and dead wood)

A. How many prefire samples have been collected? $n =$ 12.

B. How close must your value of fuel moisture content be for your intended project? ± 1 percent.

C. Using your prefire samples, list one set of collected moisture content samples below:

	x	x^2		x	x^2
1.	7	49	11.	7	49
2.	9	81	12.	6	36
3.	8	64	13.		
4.	7	49	14.		
5.	6	36	15.		
6.	8	64	16.		
7.	9	81	17.		
8.	10	100	18.		
9.	9	81	19.		
10.	8	64	20.		

D. Add all the values of x: $\Sigma x =$ 94.

E. Multiply each value by itself (x^2) and add all the values:

$\Sigma x^2 =$ 754.

F. Multiply the value in D by itself and divide by the value in A:

$(\Sigma x)^2/n =$ $94 \times 94/12 = 736.3$.

Appendix B—Continued

Sample Density Worksheet Example—Continued

G. Subtract the value in F from the value in E:

$\Sigma x^2 - (\Sigma x)^2/n =$ 17.7 .

H. Subtract 1 from the value in A: $(n - 1) = df =$ 11 .

I. Divide the value in G by the value in H: $(\Sigma x^2 - (\Sigma x)^2/n) / (n - 1)$

$= s^2 =$ 17.7/11 = 1.6 .

J. What is your acceptable moisture content error? ± 1 percent.

K. How sure (percent) do you want to be that you will be within your range of acceptable error? $P =$ 90 percent.

L. Take the value in K, subtract it from 100, and divide the result by 100:

$(100 - P) / 100 =$ probability = (100 − 90)/100 = 0.10 .

M. Go to a t table and down the left-hand column under "df" to the value in H, and across to the right to the column under the probability value in L.

List the value at the intersection: $t =$ 1.796 .

N. Multiply the value in J by itself: $E^2 =$ 1 .

O. Multiply the value in M by itself: $t^2 =$ 3.23 .

P. Multiply the value in I by the value in O and divide by the value in N:

$(t^2 s^2) / E^2 = m =$ 5.2 .

Q. Round to the next higher integer 6 .

This is the number of samples you must collect next time to be sure you will achieve your acceptable precision in estimating the moisture content of the selected fuel.

Appendix C

Sample Density Worksheet

I. Previous data (fuel, ____________________).

A. How many prefire samples have been collected? $n =$ __________.

B. How close must your value of fuel moisture content be for your intended project? ± __________ percent.

C. Using your prefire samples, list one set of collected moisture content samples below:

	x	x^2		x	x^2
1.	________	________	11.	________	________
2.	________	________	12.	________	________
3.	________	________	13.	________	________
4.	________	________	14.	________	________
5.	________	________	15.	________	________
6.	________	________	16.	________	________
7.	________	________	17.	________	________
8.	________	________	18.	________	________
9.	________	________	19.	________	________
10.	________	________	20.	________	________

D. Add all the values of x: $\Sigma x =$ __________.

E. Multiply each value by itself (x^2) and add all the values:

$\Sigma x^2 =$ __________.

F. Multiply the value in D by itself and divide by the value in A:

$(\Sigma x)^2/n =$ ________________.

Appendix C—Continued

Sample Density Worksheet—Continued

G. Subtract the value in F from the value in E:

$\Sigma x^2 - (\Sigma x)^2/n =$ ____________.

H. Subtract 1 from the value in A: $(n - 1) = df =$ ____________.

I. Divide the value in G by the value in H: $(\Sigma x^2 - (\Sigma x)^2/n)/(n - 1)$

$= s^2 =$ ____________.

J. What is your acceptable moisture content error? ± ____________ percent.

K. How sure (percent) do you want to be that you will be within your range of

acceptable error? $P =$ ____________ percent.

L. Take the value in K, subtract it from 100, and divide the result by 100:

$(100 - P)/100 =$ probability = ____________________________.

M. Go to a *t* table and down the left-hand column under "*df*" to the value in H, and across to the right to the column under the probability value in L.

List the value at the intersection: $t =$ ____________.

N. Multiply the value in J by itself: $E^2 =$ ____________.

O. Multiply the value in M by itself: $t^2 =$ ____________.

P. Multiply the value in I by the value in O and divide by the value in N:

$(t^2 s^2)/E^2 = m =$ ____________.

Q. Round to the next higher integer ____________.

This is the number of samples you must collect next time to be sure you will achieve your acceptable precision in estimating the moisture content of the selected fuel.

ppendix D

ata Sheet for Field Use

Location ____________________

Site No. ____________________

Fuel moisture,
black spruce
sites

Observer ____________

Date ____________
Month/day/year

Time ____________

Material	Can number
Upper moss + lichens	
Lower moss + lichens	
Upper duff (2 to 2.5 inches)	
Lower duff (4.5 to 5 inches)	
Blueberry	
Cranberry	
Labrador tea	
Black spruce	

Phenology
Blueberry
Cranberry
Labrador tea
Black spruce
Comments:

Appendix E

Data Sheet for Laboratory Use

Location ____________________

Site No. ____________________

Fuel moisture calculations, black spruce sites

Date in oven ____________________

Date out of oven ____________________
Month/day/year

Observer ____________________

Time in ____________________

Date collected ____________________

Time out ____________________

Time collected ____________________

Material	Can No.	Tare weight	Wet weight	Dry weight	Moisture content
Upper moss + lichens					
Lower moss + lichens					
Upper duff					
Lower duff					
Blueberry					
Cranberry					
Labrador tea					
Black spruce					

Comments:

Norum, Rodney A.; Miller, Melanie. Measuring fuel moisture content in Alaska: standard methods and procedures. Gen. Tech. Rep. PNW 171 U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984** 34 p.

Methods and procedures are given for collecting and processing living and dead plant materials for the purpose of determining their water content. Wild-land fuels in Alaska are emphasized, but the methodology is applicable elsewhere. Guides are given for determining the number of samples needed to attain a chosen precision. Detailed procedures are presented for collecting fuel samples in the field, transporting them safely, and handling them in the laboratory. General guidelines for all live fuels and specific techniques for individual species are given.

Keywords: Fuel moisture content, fuels (forest fire), fire (forest), Alaska.

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PART 1 OF 2 1984

WILDLIFE HABITATS IN MANAGED RANGELANDS-- THE GREAT BASINS OF SOUTHEASTERN OREGON

THE RELATIONSHIP OF TERRESTRIAL VERTEBRATES TO PLANT COMMUNITIES AND STRUCTURAL CONDITIONS

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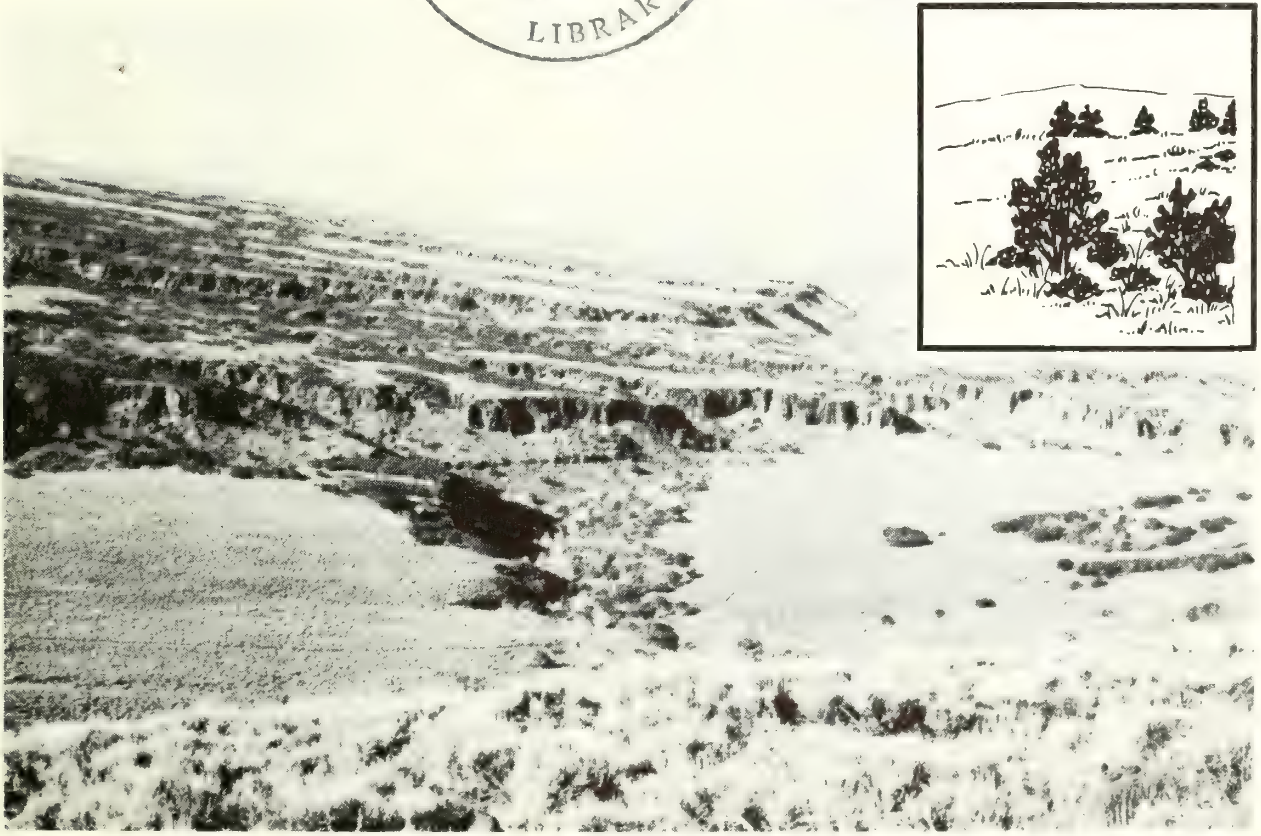

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

ABSTRACT

The relationships of terrestrial vertebrates to plant communities, structural conditions, and special habitats in the Great Basin of southeastern Oregon are described. The importance of habitat components to wildlife and the predictability of management activities on wildlife are examined in terms of managed rangelands. The paper does not provide guidelines but rather shows a method of determining the consequences of potential management actions. The series of relationships discussed in Part 1 are given in the appendices that are in a companion publication, General Technical Report PNW-172, Part 2.

THE AUTHORS

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This publication is part of the series **Wildlife Habitats in Managed Rangelands—The Great Basin of Southeastern Oregon.** The purpose of the series is to provide a range manager with the necessary information on wildlife and its relationship to habitat conditions in managed rangelands in order that the manager may make fully informed decisions.

The information in this series is specific to the Great Basin of southeastern Oregon and is generally applicable to the shrub-steppe areas of the Western United States. The principles and processes described, however, are generally applicable to all managed rangelands. The purpose of the series is to provide specific information for a particular area but in doing so to develop a process for considering the welfare of wildlife when range management decisions are made.

The series is composed of 14 separate publications designed to form a comprehensive whole. Although each part will be an independent treatment of a specific subject, when combined in sequence, the individual parts will be as chapters in a book.

Individual parts will be printed as they become available. In this way the information will be more quickly available to potential users. This means, however, that the sequence of printing will not be in the same order as the final organization of the separates into a comprehensive whole.

A list of the publications in the series, their current availability, and their final organization is shown on the inside back cover of this publication.

Wildlife Habitats in Managed Rangelands—The Great Basin of Southeastern Oregon is a cooperative effort of the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, and United States Department of the Interior, Bureau of Land Management.

Introduction

The Federal rangeland manager must account for the impacts—whether good or bad—of management activities on all species of wildlife. The legal challenges, reviews, and court opinions that have emerged from conflicts over management of Federal rangeland have raised questions for which the land manager has had inadequate answers.

"Wildlife" has assumed a broader meaning in the last decade. No longer is wildlife defined by most land managers in terms of game species or confined to a relatively few species of special interest. The increasing recognition of ecological principles—everything is connected to everything else, and there is no such thing as a "free lunch" (Commoner 1971)—makes it mandatory that managers take a more holistic view of the system that they manage (Likens and Bormann 1972, McKell 1975, Maser and Thomas 1978, Odum 1969). For example, which species of wildlife will be adversely influenced, which benefited, and which unaffected by range management activities? What is the degree of impact on those species? How will the influences vary over time? Which negative impacts are irreversible and which can be reduced by appropriate management activity? Which species are especially sensitive to habitat change and how will they respond to habitat alterations? Which species are threatened and endangered and how will they be influenced?

Our purpose is to show how the range manager can deal with these problems in range management planning. The system described is designed to handle a large volume of technical information about wildlife and their habitats in a way that makes sense to the range manager. The approach was adapted from the work of Thomas et al. (1979) that, along with the contributions of Patton (1978), forms the basis for the Wildlife Habitats Relationships program of the USDA Forest Service. This national program will provide the approach and data base for the consideration of wildlife habitat in land-use planning on the National Forests. It is our intent to demonstrate the applicability of the technique and the approach to planning efforts on managed rangelands.

The first task was to assemble all pertinent data for the 341 species of vertebrates in the Great Basin of southeastern Oregon. The amount of data varied from extensive for some species to almost nothing for others. This presented two problems—what to do when information was inadequate and how to present information on a large number of species without overwhelming the manager with detail.

The second task was to weigh the impacts of range management activities on wildlife. There are basically two ways to consider wildlife in rangeland planning and management (Call 1978). The more traditional way is to develop management plans for one or several species of prime interest. But this does not take into account the habitat needs of all species. The approach used here is to consider habitat as the prime determinant of wildlife welfare and to associate wildlife with habitat condition.

Wildlife habitats also had to be identified in such a way that they could be considered simultaneously with range management for livestock. This was done by equating plant communities and their structural conditions with habitats for wildlife. (These structural conditions are: grass-forb → low shrub → tall shrub → tree → tree/shrub. As a plant community progresses from the grass-forb condition through the tree/shrub condition, the cumulative effect of the existing plant species' growth forms increases the structural diversity of the plant community or condition. For example, a grass + a forb condition has a certain diversity of structure, but a grass + a forb + a shrub + a tree obviously has a far greater diversity of structure. Since this structural diversity is measurable, both qualitatively and quantitatively, we use the term structural condition.)

Previous applications of this approach have used plant communities and successional stages as the primary habitat classification (Thomas et al. 1979, Verner and Boss 1980). These efforts dealt primarily with forested areas where succession is better understood, more predictable, and more obvious than in rangeland conditions. Within rangeland plant communities, however, there is an array of structural conditions that are recognizable and can be interpreted as a habitat condition. We therefore used structural conditions by plant community as the descriptor of habitats. These structural conditions are the result of the natural growth and development of plant communities, as altered by management activities such as controlling brush, grazing with domestic livestock and wild ungulates, fencing, maintenance of grazing systems, planting or seeding trees or grass, and thinning forest stands. The plant community was accepted as an integrator of all environmental variables on the site (Daubenmire 1975, 1976; Feldhamer 1979; Sauer and Uresk 1976). By associating individual wildlife species and groups of species with plant communities and an array of structural conditions (fig. 1), the rangeland manager can translate standard range inventories into information on wildlife habitats.

Only enough information is presented in this paper (Part 1) to describe the principles and procedures on which the wildlife relationships for the Great Basin in southeastern Oregon are based. Ecological information for all terrestrial vertebrates is included in the appendices that form Part 2 of General Technical Report PNW-172. This companion publication is primarily of interest to persons working in the geographical area described. Those who need the appendices should refer to the following:

Maser, Chris; Thomas, Jack Ward; Anderson, Ralph G. Wildlife habitats in managed rangelands—the Great Basin of southeastern Oregon: the relationship of terrestrial vertebrates to plant communities and structural condition. Gen. Tech. Rep. PNW-172, part 2 of 2 parts. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1984. 237 p.

Copies may be obtained from either of the following:

Oregon State Office
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P.O. Box 2965
Portland, OR 97208

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P.O. Box 3890
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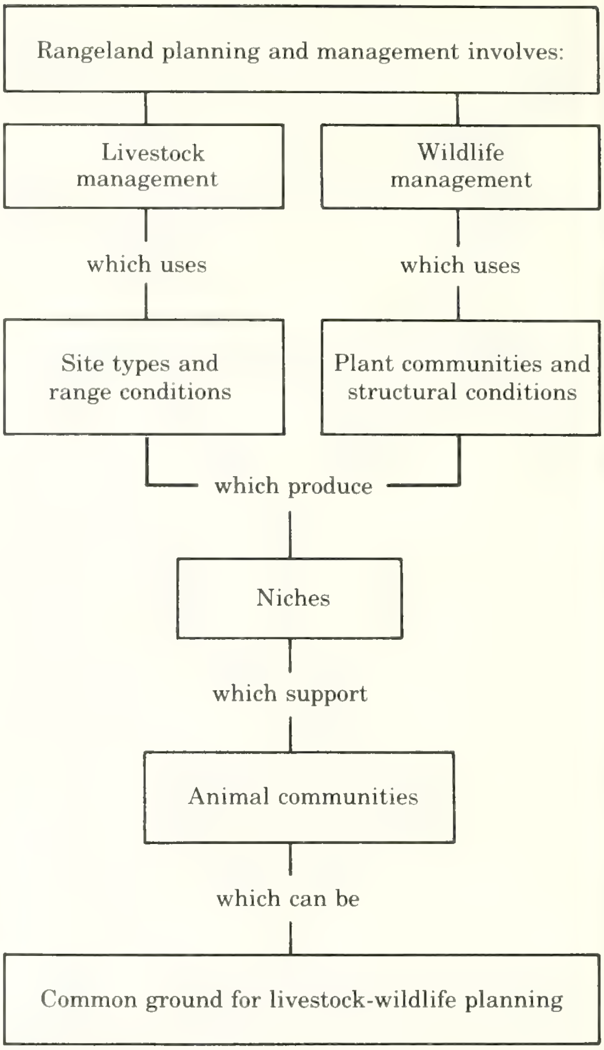

Rangeland planning and management involves:
Livestock management
Wildlife management
which uses
which uses
Site types and range conditions
Plant communities and structural conditions
which produce
Niches
which support
Animal communities
which can be
Common ground for livestock-wildlife planning

Figure 1.—Plant communities and their structural conditions can be a common ground for livestock-wildlife planning.

Plant Community Descriptions

The starting point for describing the plant communities was the classification of the ecosystems of the Great Basin in southeastern Oregon by Dealy et al. (1981). This classification required some modification to bring it in line with other systems already in use by rangeland managers. Because most wildlife respond more to vegetative structure than to plant species composition (Black 1968, Larrison and Johnson 1973, Maser and Thomas 1978, Olson

1974, Rotenberry and Wiens 1980, Tester and Marshall 1961, Turcek 1972), structurally similar ecosystems were grouped and others were divided or identified as structurally distinct and important wildlife habitats. In other words, ability of plant ecologists to differentiate between plant communities exceeds the present ability of wildlife biologists to detect differences in animal communities. When no demonstrated differences existed in animal communities between structurally similar plant communities, the communities were combined.

The modifications described in figure 2 show the relationship between the ecosystems described by Küchler (1964) and Dealy et al. (1981).

Wildlife Habitat Relationships

Wildlife habitats and their structural conditions have unique environmental conditions that are ecologically important as habitat niches for wildlife species (fig. 3). The habitat niches are a product of the plant community, its structural conditions, and other environmental factors—including soil type, moisture regime, microclimate, slope aspect, elevation, and temperature. The complex interactions of site and plant community structure could be dissected and the more precise influence of each on the animal community determined. If such information existed, it would probably be too complex to use readily. The plant community type, however, can be considered an integrator of the many factors interacting on the site.

Wildlife species are individually adapted to combinations of plant community and structural condition for feeding, or reproduction, or both. These wildlife-habitat relationships provide the basic information from which the informational displays (tables, figures, and companion appendices) were developed. Depending on their requirements, rangeland managers and planners can extract information at four levels of detail. The amount of detail increases with each level:

Level 1. The relationship of animal life forms for feeding and reproduction to plant communities and plant community structural conditions. Life forms are groups of wildlife species that exhibit similar habitat requirements for both feeding and reproduction.

Level 2. The relationship of individual species for feeding and reproduction to plant communities and plant community structural conditions.

Level 3. A summary of the available biological data for each species.

Level 4. Selected references on habitat relationships for each species. Examination of these references and their bibliographies can provide the user with more detailed data and additional sources of information.

The information on each species in level 2 has been used to develop a relative measure of vulnerability of each species to habitat manipulation. This is another source of information for the manager's use.

The informational displays were constructed from: (1) the literature, (2) interpretation and extrapolation of information in that literature, (3) 3 years of fieldwork in the area, and (4) a consensus of cooperating wildlife biologists. In all cases, in our judgment, the best available information was used. If the literature was specific to the Great Basin of southeastern Oregon and, in our opinion, contained the required information, it was used. If the literature was not specific to the area or habitat condition, it was adapted as appropriate. In the absence of published information or field data, the relationship of the species to habitat was determined by consensus of the consulting biologists. Data for the most intensively studied species were, naturally, more voluminous and detailed than for relatively obscure species. As new information becomes available, it can be added to the system.

Natural vegetation as described by Küchler (1964)	Communities of the Great Basin in southeastern Oregon as described by Dealy et al. (1981)	Plant communities as used here to describe animal habitats
37 Mountainmahogany-oak shrub (similar position – not equal)	Curlleaf mountainmahogany/mountain big sagebrush/bunchgrass Curlleaf mountainmahogany/mountain snowberry/grass	Curlleaf mountainmahogany/shrub
	Curlleaf mountainmahogany/pinegrass	Curlleaf mountainmahogany/pinegrass
	Curlleaf mountainmahogany/Idaho fescue Curlleaf mountainmahogany/bearded bluebunch wheatgrass – Idaho fescue	Curlleaf mountainmahogany/bunchgrass
No provision	Squaw apple/bunchgrass	Squaw apple/bunchgrass
55 Sagebrush steppe (with juniper)	Western juniper/big sagebrush/bearded bluebunch wheatgrass Western juniper/big sagebrush/Idaho fescue	Juniper/sagebrush/bunchgrass
55 Sagebrush steppe	Basin big sagebrush/bunchgrass Wyoming big sagebrush/bunchgrass Mountain big sagebrush/bunchgrass Threetip sagebrush/bunchgrass Bolander silver sagebrush/bunchgrass Mountain silver sagebrush/bunchgrass Subalpine big sagebrush/bunchgrass	Tall sagebrush/bunchgrass
	Stiff sagebrush/bunchgrass Low sagebrush/bunchgrass Cleftleaf sagebrush/bunchgrass Early low sagebrush/bunchgrass Black sagebrush/bunchgrass	Low sagebrush/bunchgrass
40 Saltbush-greasewood	Black greasewood/grass	Black greasewood/grass
	Shadscale saltbush/bunchgrass	Shadscale saltbush/bunchgrass
No provision	Riparian	Riparian
	Permanently wet meadows	Permanently wet meadows
	Seasonally wet meadows	Seasonally wet meadows
	Quaking aspen/mountain big sagebrush	Quaking aspen/mountain big sagebrush/bunchgrass
	Quaking aspen/grass	Quaking aspen/grass
52 Alpine meadows and barren (similar – not equal)	Subalpine bunchgrass	Subalpine bunchgrass
No provision	No provision	Crested wheatgrass (seeded)

[1] Scientific names are given in appendix 14.

Figure 2.—Relationships between plant communities described in this chapter and two other plant classification systems.

	Structural conditions				
Environmental variable	Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
Vegetation height	•	••	•••	•••••	•••••
Canopy closure	•	•••	••••	•••	•••••
Canopy volume	•	•••	••••	•••	•••••
Plant diversity	••	•••	•••	•	•••
Structural diversity	•	••	•••	••••	•••••
Forage production	•••••	•••	••••	••	•
Browse production	•	••••	•••••	••	•••
Animal diversity	•	••	•••	••••	•••••

Figure 3.—Generalized structural conditions of range and related environmental variables. The number of dots do not reflect relative values, but a range from • = least to ••••• = most.

Level 1: Life Form Association With Plant Communities And Successional Stages

The large number of wildlife species present in most areas makes it difficult for the land manager to account for them in the land-use planning process. In the case of the Great Basin this number was reduced from 341 species (appendix 1, Part 2) to 16 life forms (table 1, this paper). The relationship of the species to their habitats is the basis for grouping them into life forms. This life form concept was adapted by Thomas et al. (1979) from Haapanen's (1965) division of birds of the Finnish forests into groups based on specific combinations of habitat requirements for reproduction and feeding. The concept was expanded to include all terrestrial vertebrates. The species are also listed phylogenetically by their common and scientific names in appendix 1 and alphabetically by computer codes in appendix 2.

Grouping species by life forms is distinctly different from the usual grouping of species by morphological characteristics. It enables the rangeland manager to evaluate the response of wildlife to habitat much more readily than if each species were considered individually. If this concept is applicable in land-use planning, new and different life forms will most likely be developed. They can be changed as needed to fit the circumstances. This concept can be used to satisfy the planning requirements of the regulations issued pursuant to the Federal Land Policy and Management Act (U.S. Laws, Statutes, etc., Public Law 94-579, 1976) and to the National Forest Management Act (U.S. Laws, Statutes, etc., Public Law 94-588, 1976), which requires management by "indicator species" and requires identification of the wildlife where welfare is reflected by the welfare of the indicator.

The relationship of vertebrate life forms to plant communities and structural conditions is shown in appendix 3, to overstory and understory in table 2, and is summarized by overstory in appendix 4. Seventy-two of the 341 species that occur in the Great Basin of southeastern Oregon do not appear in this listing or in subsequent discussions. Seventy bird species either migrate through or are incidental in the Great Basin of southeastern Oregon. The bullfrog and the spotted frog, the only species in life form 1, have also been omitted as they are semiterrestrial. The 70 bird species and the 2 mammals excluded are listed in appendix 5.

Life form 7 is used as an example of how the system works. The species in life form 7 feed in shrubs, trees, or air, and reproduce in shrubs. In the Great Basin in southeastern Oregon, the life form contains 29 species.

Much useful information can be derived from the following data sets. Table 2, for example, shows that: (1) life form 7 is strongly associated with shrub-dominated communities, (2) some shrub-dominated communities, such as juniper/sagebrush/bunchgrass, curlleaf mountain-mahogany/shrub, quaking aspen/bunchgrass,

Table 1—Life form descriptions

Life form	Reproduces	Feeds	No. of species[1]	Examples
1	in water	in water	2	bullfrog
2	in water	on ground, in shrubs and/or trees	6	long-toed salamander, western toad, Pacific treefrog
3	on ground around water or on floating or emergent vegetation	in water, on ground, in shrubs and trees	44	common garter snake, killdeer
4	in cliffs, caves, rims, and/or talus	on ground or in air	33	western fence lizard, common raven, spotted skunk
5	on ground without specific water, cliff, rim, or talus association	on ground	45	short-horned lizard, northern junco, mule deer
6	on ground	in shrubs, trees, or air	4	common nighthawk, orange-crowned warbler
7	in shrubs	on ground, in water or air	29	American robin, Swainson's thrush, chipping sparrow
8	in shrubs	in shrubs, trees, or air	5	yellow-billed cuckoo, bushtit
9	primarily in deciduous trees	in shrubs, trees, or air	3	house finch
10	primarily in conifers	in shrubs, trees, or air	10	pinyon jay, Townsend's warbler
11	in trees	on ground, in shrubs, trees, or air	13	sharp-shinned hawk, American crow
12	on very thick branches	on ground or in water	6	great blue heron, golden eagle
13	excavates own hole in a tree	on ground, in shrubs, trees, or air	9	common flicker, Williamson's sapsucker
14	in a hole made by another species or naturally occurring	on ground, in water, or air	25	American kestrel, mountain bluebird
15	underground burrow	on or underground	32	burrowing owl, kit fox
16	underground burrow	in water, on ground, or in air	9	bank swallow, muskrat
	Total species		275	

[1] Species assignment to life form is based on predominant habitat-use patterns.

Table 2—Relative degree of use of plant communities and structural conditions by wildlife species in life form 7 (source: appendix 3)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

		Structural conditions														
		grass-forb			low shrub			tall shrub			tree			tree/shrub		
Plant community	Function	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.
crested wheatgrass (seeded)	R 0		0	0												
	F 1		1	1												
subalpine bunchgrass	R 0		0	0												
	F 1		1	1												
permanently wet meadows	R 3		3	0												
	F 10		8	1												
seasonally wet meadows	R 3		3	0												
	F 10		8	0												
shadscale saltbush/ bunchgrass	R 0		0	0		0	0									
	F 9		4	1		6	4									
low sagebrush/bunchgrass	R 4		0	0		0	0									
	F 14		5	2		8	6									
black greasewood/grass	R 1		0	0		0	0		0	1						
	F 12		5	2		9	6		12	9						
tall sagebrush/bunchgrass	R 18		3	0		6	3		18	14						
	F 21		5	2		12	10		21	18						
squaw apple/bunchgrass	R 2		0	0		1	1		2	2						
	F 15		4	1		11	8		15	12						
curlleaf mountainmahogany/ bunchgrass	R 4		0	0		1	1		4	4		2	2			
	F 19		6	2		13	10		19	16		14	12			
curlleaf mountainmahogany/ pinegrass	R 4		0	0		1	1		4	4		2	2			
	F 19		6	2		13	10		19	16		14	12			
juniper/sagebrush/ bunchgrass	R 18		2	0		4	2		17	13		11	7		18	14
	F 25		8	2		15	11		25	20		19	15		25	21
curlleaf mountainmahogany/ shrub	R 14		0	0		2	2		13	11		7	4		13	10
	F 26		8	2		15	11		26	21		20	16		26	22
quaking aspen/grass	R 19		3	0		4	1		19	11		14	7		18	11
	F 24		9	2		14	10		24	17		20	14		24	18
quaking aspen/mountain big sagebrush/bunchgrass	R 25		3	0		6	3		25	17		15	8		24	17
	F 28		9	2		15	11		28	21		22	16		28	22
riparian	R 23		3	0		4	1		21	14		14	7	1	22	15
	F 25		10	3		14	10		24	17		20	14	0	24	18

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

quaking aspen/mountain big sagebrush, and riparian, are disproportionately important, and (3) the tall shrub, tree, and tree/shrub structural conditions are critical. Reproductive and feeding orientation to plant community types and plant community structural conditions can be determined for the entire life form.

By examining the relationship of the life form to plant communities and their structural conditions, the rangeland manager can judge the impact of range mangement practices on the life form (Reynolds and Trost 1979, 1980, 1981; Rogers and Hedlund 1980). This is done by determining the importance (expressed by the number of species) of a particular structural condition of a community. The impact of a contemplated management action is determined by comparing the two numbers for the structural conditions involved.

Consider, for instance, the importance of the juniper/sagebrush/bunchgrass community in the tree/shrub/annuals structural condition. Of the 29 species in the life form, 25 feed and 18 reproduce there. Suppose a manager is contemplating two courses of action on a particular area: (1) removing the trees and shrubs to enhance forage production for domestic and wild ungulates, thereby altering the vegetative condition to the grass-forb stage or (2) encourage the replacement of the annual vegetation with mature bunchgrasses. What are the consequences of each alternative to life form 7?

Reduction to the grass-forb structural condition would reduce to 0 the number of species reproducing and to 2 the number finding feeding habitat. This extremely adverse impact would continue for about 10-20 years after initial regeneration of the juniper and sagebrush. At that time, the stand would enter the structural condition (tall shrub with bunchgrasses) where 20 species feed and 13 reproduce. Full recovery of the habitat for life form 7 would not occur until the stand was about 40-60 years old and had returned to the tree/shrub/annuals structural condition.

A decision to allow the stand to progress from the tree/shrub/annuals structural condition to the tree/shrub/bunchgrass state would have a small negative effect on the life form because 21 species feed and 14 species reproduce there.

Obviously, if the manager considered factors such as the percentage of the area affected, the distribution of plant communities and structural conditions, and anticipated changes over time, a more sophisticated analysis could be made. But the same basic comparisons would be used.

The displays in appendix 3 can be used to predict the response of animal life to all alterations in the plant community, whether artificial or natural. Such alterations could result from natural phenomena, such as fire, insect infestation, or windstorm, or from management activities like seeding, planting, herbicide treatment, or fertilization.

Any of these actions would change the structural condition to another state—usually a more simplified one (table 3) (Mack 1981, Rickard and Cline 1980, Thomas et al. 1979). For example, planting trees introduces another vegetative layer and adds diversity, but wildfire removes trees and shrubs and simplifies the vegetative structure. Because wildlife is mainly a product of the vegetative structure of a community and not the age of the vegetation, it is possible to predict the effect of various manipulations of vegetation on wildlife.

Level 2: Relationship of Species To Plant Communities And Structural Conditions

The responses of vertebrate life forms to plant communities and structural conditions can be generalized. But the response of each species within a life form varies because of specific habitat requirements. Level 2 shows orientation to plant community and structural conditions for each species. Species are grouped by life form to facilitate comparison with information in level 1. The primary orientation to plant communities by species within life forms is illustrated for life form 7 in table 4. Similar information for all life forms is in appendix 6. Information on species orientation to structural conditions is illustrated in table 5; complete information for all life forms is in appendix 7.

Table 3—Anticipated changes in range-community structural conditions due to management action

Management action	Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
Weed control	◄	►	►	–	–
Brush control:					
Chemical		◄	◄		◄
Mechanical		◄	◄		◄
Biological		◄	◄		◄
Tree control:					
Chain and doze				◄	◄
Clearcutting				◄	◄
Shelterwood				◄	◄
Thin				◄	◄
Salvage				◄	◄
Debris disposal				◄	◄
Controlled burn:					
Cold	◄	◄	◄	–	◄
Hot	◄	◄	◄	◄	◄
Seeding and planting:					
Grasses and forbs	►	◄	◄	◄	◄
Shrubs	►	–	–	►	–
Trees	►	►	►	–	–
Fertilization	–	◄►	◄►	◄►	◄►
Mechanical soil treatment:					
Pitting	◄	◄	◄	◄	◄
Contouring	◄	◄	◄	◄	◄
Water:					
Water spreading	◄	◄	◄	◄	◄
Drainage	►	►	►	►	►
Water development	◄	◄	◄	–	–
Grazing:					
Cattle	◄►	◄►	◄►	–	–
Horses	◄►	◄►	◄►	–	–
Sheep	◄►	◄	◄	–	◄
Goats	◄►	◄	◄	–	◄

► increased structural diversity;
◄ decreased structural diversity;
◄► increases or decreases structural diversity depending upon type and/or level of application;
– no effect on structural diversity;
(blank space) not a viable practice.

Table 4—Orientation of wildlife species in life form 7 to plant communities (source: appendix 6)

● – Primary (≥40%) reproduction and feeding

0 – Secondary (<40%) reproduction and feeding

R – Primary (≥40%) reproduction only

r – Secondary (<40%) reproduction only

F – Primary (≥40%) feeding only

f – Secondary (<40%) feeding only

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgr.	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper/sagebrush/bunchgr.	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	Number of plant communities used by each species for: R	F
	BIRDS																	R	F
BUST	green heron																●	1	1
BUIB	cattle egret	f		F	F				0						●	●	●	3	5
NYNY	black-crowned night heron			F	F				0						●	●	●	3	5
BUSW	Swainson's hawk			f	f	f	F	F	●	f	F	F	●	F	●	●	●	5	10
STCAL	calliope hummingbird			F	F								●	●	●	●	●	5	7
CAAN	Anna's hummingbird			F	F								●	●	●	●	●	5	7
TYTY	eastern kingbird						f	f	●	f	F	F	●	●	●	●	●	6	8
EMTR	willow flycatcher					F	F	F	F	F	F	F	F	F	●	●	●	3	12
EMWR	gray flycatcher					F	F	F	●	F	●	●	●	●	●	●	F	7	12
APCO	scrub jay			F	F		f	f	●	f	●	●	●	●	F	F	●	6	10
PIPI	black-billed magpie	F	F	F	F	F	F	F	●	●	●	●	●	●	●	●	●	9	16
DUCA	gray catbird						f	f	F	F	F	F	F	F	●	●	●	3	9
TORV	brown thrasher					f	●	F	●	F	F	F	●	●	F	●	●	6	11
ORMO	sage thrasher						F	F	●	F	f	f	●	●	f	●	f	4	7
TUMI	American robin			F	F				f		F	F	F	F	●	●	●	3	9
CAUS	Swainson's thrush						f	f	●	f	F	F	F	F	●	●	●	4	8
PACAE	blue-gray gnatcatcher								●	f	f	f	●	F	F	●	F	3	6
LALU	loggerhead shrike					F	F	●	●	F	F	F	●	●	F	F	●	5	12
AGPH	red-winged blackbird			●	●	F	F	F	●	F	F	F	F	F	●	●	●	6	14
EUCY	Brewer's blackbird	f		●	●	F	F	F	●	F	F	F	●	F	●	●	●	7	14
MOAT	brown-headed cowbird	f		●	●	F	F	F	●	F	F	F	●	F	●	●	●	7	14
PAAMO	lazuli bunting								f	f	f	f	f	F	●	●	●	3	4
CAPS	lesser goldfinch								f	F	F	F	F	●	●	●	●	4	8
PICH	green-tailed towhee					F	F	F	●	●	●	●	F	●	F	●	f	6	11
PIER	rufous-sided towhee					f	f	f	●	F	F	F	●	●	●	●	●	6	9
AMBE	sage sparrow						●	f	●	f	f	f	●	●	f	●	f	5	5
SPPA	chipping sparrow							f	F	F	F	F	●	●	●	●	●	5	9
SPBRE	Brewer's sparrow						●	f	●	f	f	f	●	F	f	●	f	4	5
NEMEL	song sparrow					F	●	F	●	F	F	F	●	F		F	●	4	11
	Total R	0	0	3	3	0	4	1	18	2	4	4	18	14	19	25	23		
	F	1	1	10	10	9	14	12	21	15	19	19	25	26	24	28	25		

Table 5—Orientation of wildlife species in life form 7 to structural conditions (source: appendix 7)

Structural conditions

• – Primary (≥40%) reproduction and feeding

0 – Secondary (<40%) reproduction and feeding

R – Primary (≥40%) reproduction only

r – Secondary (<40%) reproduction only

F – Primary (≥40%) feeding only

f – Secondary (<40%) feeding only

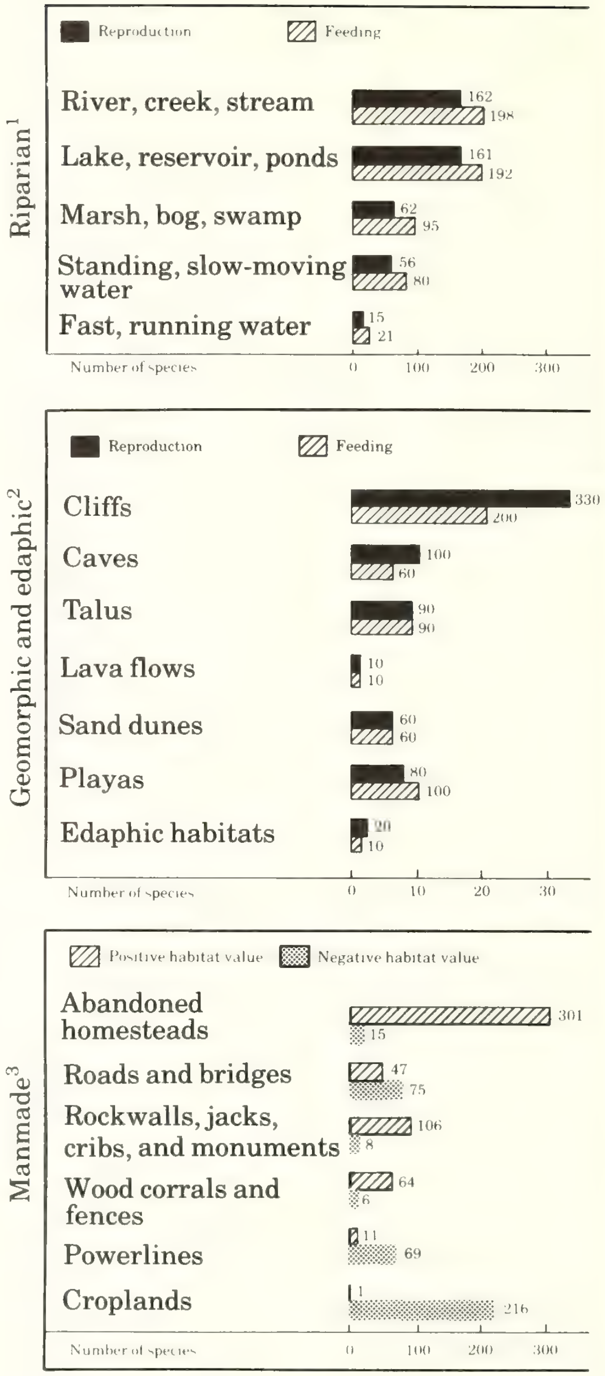
Letter code	Species	Grass-forb			Low shrub			Tall shrub			Tree			Tree shrub				
		bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	BIRDS																R	F
BUST	green heron		F	F		F	F							R	R	R	3	4
BUIB	cattle egret		F						•			•			•		3	4
NYNY	black-crowned night heron								•			•			•		3	3
BUSW	Swainson's hawk		F	F		F	F		•	•		•	•		•	•	6	10
STCAL	calliope hummingbird		F			F			•			•			•		3	5
CAAN	Anna's hummingbird		F						•			•			•		3	4
TYTY	eastern kingbird						F		•	F		•	F		•	F	3	7
EMTR	willow flycatcher					F	F		•	•		•	•		•	•	6	8
EMWR	gray flycatcher								•	•		•	•		•	•	6	6
APCO	scrub jay								•	•		F	F		•	•	4	6
PIPI	black-billed magpie		F	F		F	F		•	•		•	•		•	•	6	10
DUCA	gray catbird					F	F		•	•		f	f		•	•	4	6
TORV	brown thrasher					F	F		•	•					•	•	4	6
ORMO	sage thrasher								•	•					•	•	4	4
TUMI	American robin		F			F	f		•	•		•	•		•	•	6	8
CAUS	Swainson's thrush								•	•		F	F		•	•	4	6
PACAE	blue-gray gnatcatcher								•	•		•	•		•	•	6	6
LALU	loggerhead shrike					F	F		F	•		•	•		•	•	5	8
AGPH	red-winged blackbird		•			•			•			•			•		5	5
EUCY	Brewer's blackbird		•			•			•			•			•		5	5
MOAT	brown-headed cowbird		•			•			•			•	•		•	•	7	7
PAAMO	lazuli bunting								•	•		F	F		•	•	4	6
CAPS	lesser goldfinch					F	F		•	•		F	F		F	F	2	8
PICH	green-tailed towhee					•	•		•	•					•	•	6	6
PIER	rufous-sided towhee					•	•		•	•					•	•	6	6
AMBE	sage sparrow								•	•		F	F		•	•	4	6
SPPA	chipping sparrow								•	•		•	•		•	•	6	6
SPBRE	Brewer's sparrow					•	•		•	•		F	F		•	•	6	8
NEMEL	song sparrow								•	•					•	•	4	4
	Total R	0	3	0	0	6	3	0	27	20	0	16	9	1	28	21		
	F	0	10	3	0	16	12	0	28	21	0	22	16	0	28	22		

The use of plant communities and structural conditions by a particular species can be determined from appendices 6 and 7. Table 4 contains information on the orientation of species to plant communities for feeding and reproduction. Table 5 shows the use of structural conditions by each species. The two sets of information must be considered in tandem—one before the other. For example, the willow flycatcher shows orientation to the community for feeding only (table 4). This means that information on reproduction in table 5 should be disregarded for the willow flycatcher in the juniper/sagebrush/bunchgrass community.

Wildlife obviously have habitat requirements other than plant community and structural condition. Orientations to special habitat components are shown for all life forms in appendix 8. Orientation of species to artificial habitats is discussed by Maser et al. (1979b) and association with geomorphic and edaphic habitats by Maser et al. (1979a). The importance of these special and unique habitat components, as reflected by the number of wildlife species using them, is shown in figure 4.

Additional information may be derived from appendices 6 and 7. The total number of species oriented to each plant community and structural condition for feeding and reproduction was used to produce appendix 3 and table 2, which demonstrate the orientation of the life form. In other words, to develop the information on life form (level 1) the information for individual species in level 2 must first be completed.

The information in level 2 has a variety of uses. For example, the importance of each community and structural condition can be evaluated in terms of its ability to provide habitat for different species. In each planning scenario, the rangeland manager can examine the impact of proposed management actions on wildlife—individual species or all wildlife. The information can also be used to determine the role of plant communities as habitat for featured species or for rare and endangered species.



[1] Source: appendix 8.
[2] Source: Maser et al. 1979b.
[3] Source: Maser et al. 1979a.

Figure 4.—Number of terrestrial vertebrate wildlife species using special and unique habitats.

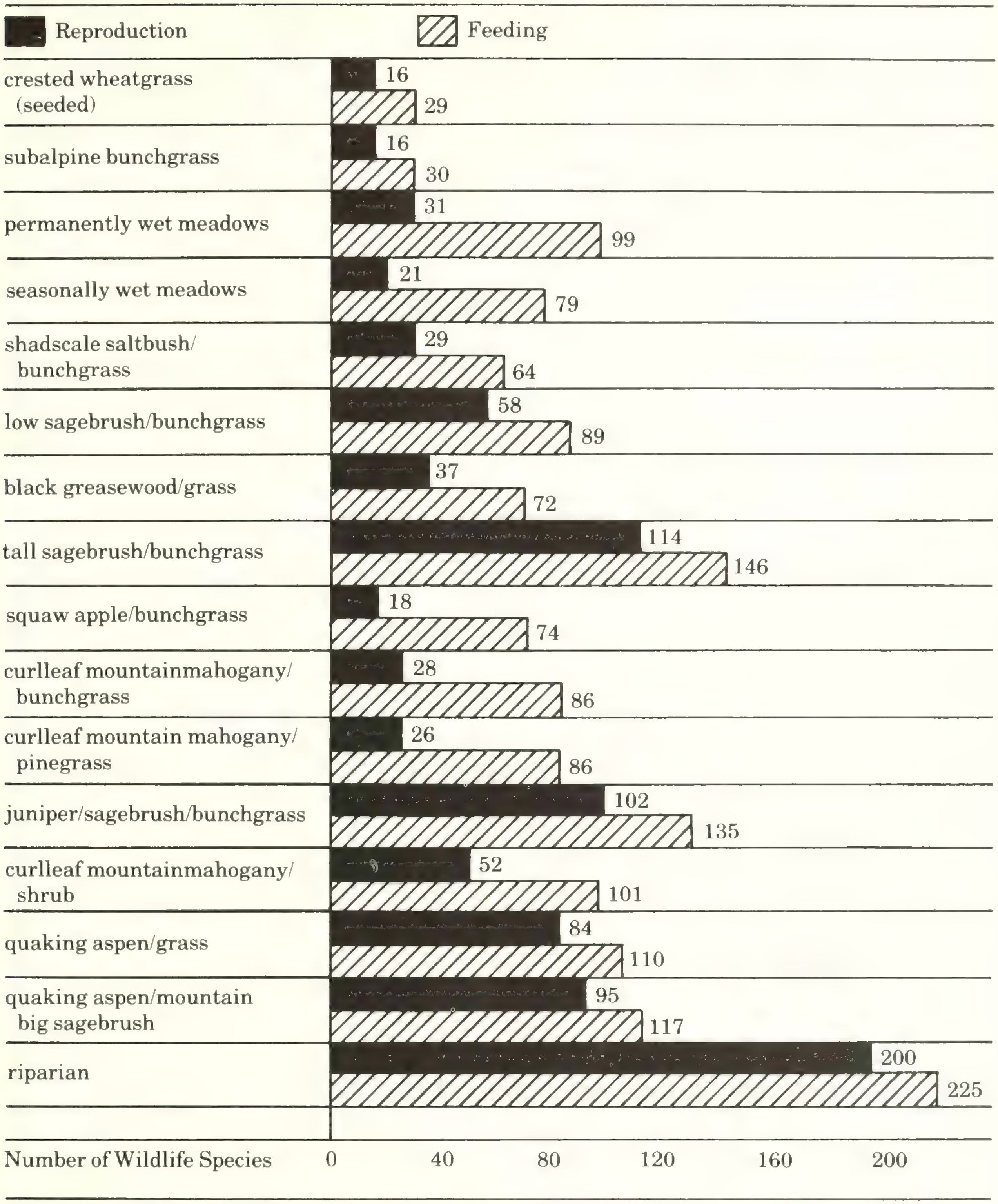


Figure 5.—Number of wildlife species oriented to desert-steppe plant communities for feeding and reproduction (source: appendix 6).

Some rangeland communities obviously produce more species of wildlife than others (fig. 5). The tall sagebrush/bunchgrass, juniper/sagebrush/bunchgrass, and riparian communities in the Great Basin of southeastern Oregon—those communities most affected by range management when enhancing forage production for domestic and wild ungulates—are also the most productive in terms of wildlife.

Figure 6 shows that the more complex structural conditions (tall shrub, tree, or tree/shrub) in the juniper/sagebrush/bunchgrass community are important to more species than are the simpler structural conditions (grass-forb and low shrub). Habitat for reproduction is also more restrictive than habitat for feeding. A similar display for all plant communities is shown in appendix 9.

Using the same data, the rangeland manager can predict the response of individual species to alterations in a structural condition. For example, a series of shrub and tree removal operations might be planned in an extensive area covered by the tree/shrub structural condition of the juniper/sagebrush/bunchgrass plant community. The intentions of the operation are to remove most of the tree and shrub canopy and to increase the density and biomass of the bunchgrasses and forbs. What wildlife species are likely to be affected? In an actual analysis, the information on each species in each life form would be examined (appendices 5 and 6). As an example, consider the data for life form 7 (table 4). Of the 29 species in life form 7, 18 (see table 4 for species' names) have a primary association with the juniper/sagebrush/bunchgrass plant community for both feeding and reproduction. In addition, seven species have a primary association and one has a secondary association for feeding only.

In this situation, what effect would removal of most of the tall shrubs and mature juniper cover have on those species? Removal or killing of the shrubs and trees would put those areas into the grass-forb structural condition. Table 5 shows that 14 of the 18 species are primarily associated with the tree/shrub/bunchgrass structural condition for both feeding and reproduction as are six of the seven showing primary orientation for feeding only. One species shows primary association to the plant community for both feeding and reproduction but only feeds in the tree/shrub/bunchgrass structural condition and reproduces in the tree/shrub/annuals structural condition. It can be concluded that such action will reduce habitat for those species by approximately 35 percent for at least 40-50 years—the time required for the stand to regenerate and reach a structural condition suitable for reoccupancy.

At the same time, some species would benefit from the early structural conditions that follow tree and shrub removal. Table 5 (or appendix 7) shows that two species (red-winged blackbird and Brewer's blackbird) would find primary nesting and feeding habitat in the changed condition and four species (cattle egret, Swainson's hawk, calliope hummingbird, and Anna'a hummingbird) would feed in such conditions. These species would gradually drop out as conditions changed back toward the original state and the original species that occupied the site might be expected to reappear.

As another example, consider the generalized relationship of wildlife in the Great Basin of southeastern Oregon to structural conditions of rangeland communities (fig. 7). This shows why many people are concerned about the effects of intensive range management to improve domestic and wild ungulate grazing on wildlife diversity and on the welfare of species that are narrowly adapted to certain structural conditions, particularly tall shrub, low shrub, tree, and tree/shrub (Baker et al. 1976, Maser and Gashwiler 1978).

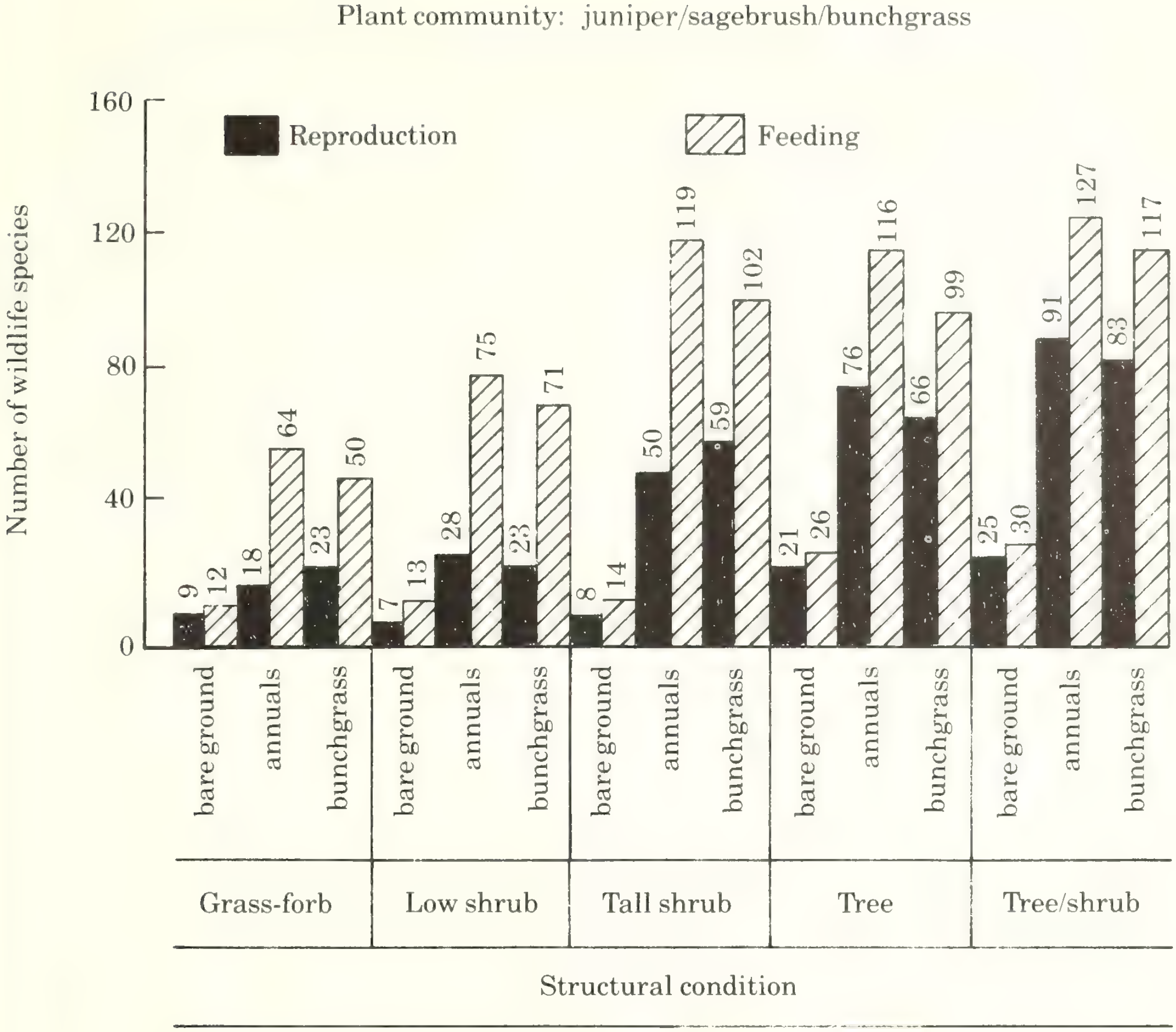


Figure 6.—Number of wildlife species associated with structural conditions in the juniper/sagebrush/bunchgrass community (source: appendix 9).

Only a few uses of such data have been illustrated. There are as many others as there are specific management questions, and new applications are being found as managers begin to use this system.

Level 3: Summary of Biological Data by Species

Level 3 is a one-line summary of key information on each species. Some of the information was derived from the appendices and some from literature reviews. Other information was drawn from the experience of wildlife biologists.

Details for each species are presented in appendix 8. Eleven species from the 29 in life form 7 are shown here as an example (table 6).

Table 6—Key information on species in life form 7 (source: appendix 8)

Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

■, □ Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				January	February	March	April	May	June	July	August	September	October	November	December		
BUST	7	green heron					▧ ░	▧ ░	▧ ░	░	░	░	░			3-6; avg. 4-5	
NYNY	7	black-crowned night heron	L				▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░			3-6	colonial nester
BUSW	7	Swainson's hawk	M			░	▧ ░	▧ ░	▧ ░	░	░	░	░			2-4	
STCAL	7	calliope hummingbird	L					░	▧ ░	▧ ░	░					2	
TYTY	7	eastern kingbird	L					▧ ░	▧ ░	▧ ░	░	░	░			3-5	aspen 3.8 ha (9.3 ac) /pr.
EMTR	7	willow flycatcher	M					▧ ░	▧ ░	▧ ░	░	░				3-4	
EMWR	7	gray flycatcher	M					▧ ░	▧ ░	▧ ░	░	░				3-4	
PIPI	7	black-billed magpie	M	░	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	6-9	
TUMI	7	American robin	M	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	3-5	juniper 1.9-3.4 ha/pr., aspen 2.3 ha (5.6 ac) /pr.
EUCY	7	Brewer's blackbird	M	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	4-6	
MOAT	7	brown-headed cowbird	M		░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░			4-6	

[1] Positive (+), negative (-), or neutral (0) net habitat associations (see chapter 13, Manmade Habitats, for fuller descriptions).

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats Riparian						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	Riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
																● ■	● ■	● ■		● ■		□	0
0.4 to 4.0 ha (1-10 ac)/ colony			■	■				○ □						● ■	● ■		● ■	● ■	■	■		□	0
nesting home range 1 pair per 6.7 km^2			□	□	□	■	■	● ■	□	■	■	● ■	■	● ■	● ■		● ■	● ■		○ □	○ □	□	+
			■	■								● ■	● ■	● ■	● ■		● ■	● ■	□	○ □	○ □	□	0
						□	□	● ■	□	■	■	● ■	● ■	● ■	● ■		● ■	● ■		○ □	○ □	□	0
breeding density: ≃0.8 ha/pr – juniper; 1.3 ha/pr – p. pine; 2.5 ha/pr – aspen					■	■	■	■	■	■	■	■	■	● ■	● ■		● ■	● ■	■	○ □	○ □	□	0
breeding density: ≃0.8 ha/pr – juniper; 1.3 ha/pr – p. pine; 2.5 ha/pr – aspen					■	■	■	● ■	■	● ■	● ■	● ■	● ■	● ■	● ■		■	■		□	□	□	0
	■	■	■	■	■	■	■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■		● ■	● ■	■	○ □	○ □	□	+
			■	■				□		■	■	■	■	● ■	● ■		● ■	● ■		○ □	○ □	□	0
	□		● ■	● ■	■	■	■	● ■	■	■	■	● ■	■	● ■	● ■		● ■	● ■		○ □	○ □	□	0
	□		● ■	● ■	■	■	■	● ■	■	■	■	● ■	■	● ■	● ■		● ■	● ■	● ■	○ □	○ □	□	0

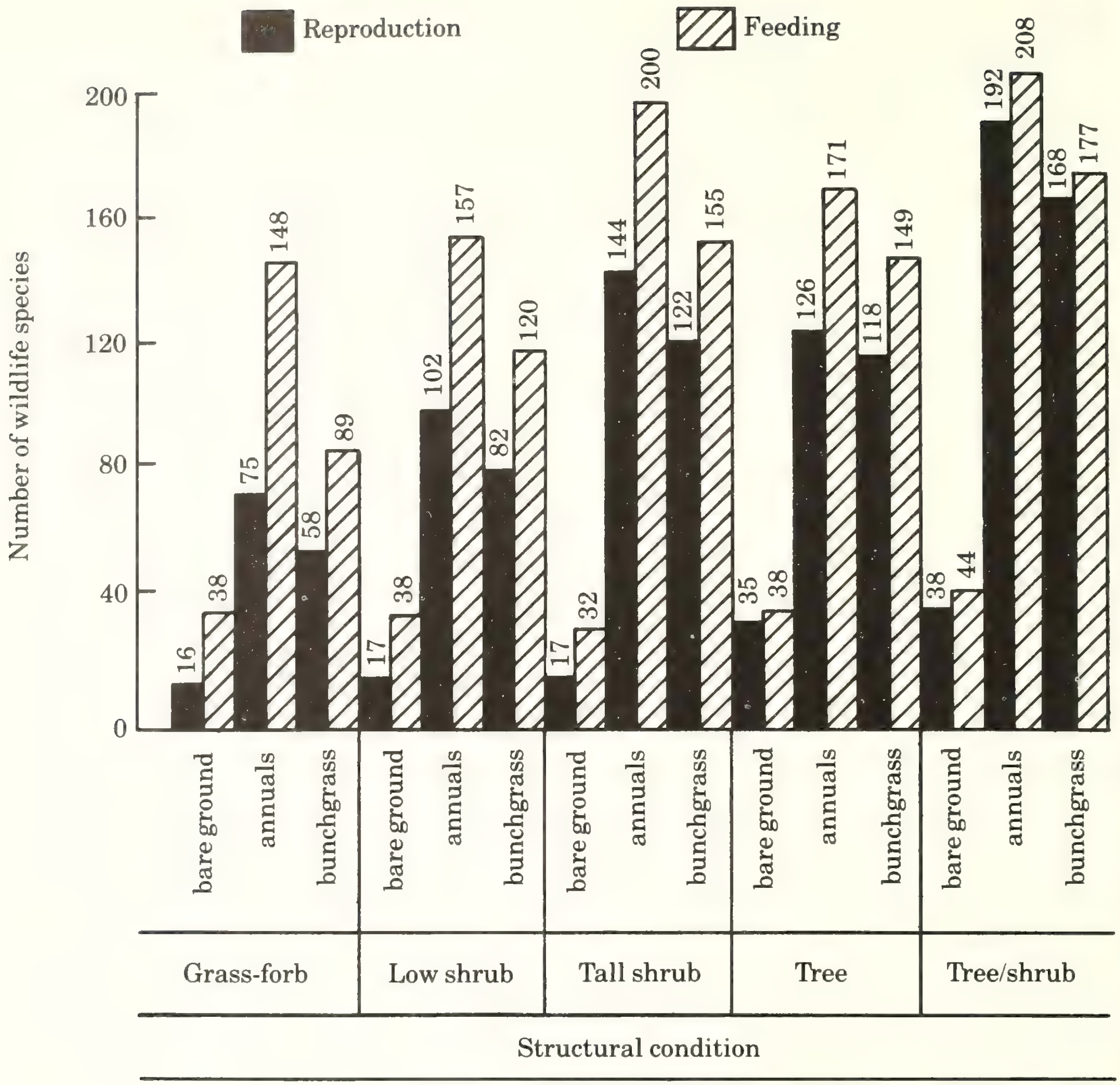


Figure 7.—Number of wildlife species oriented to desert-steppe structural conditions and the potential effect of intensive management (source: appendix 7).

Level 4: Selected References

If the information displayed so far is not sufficient, additional sources may be consulted. The most appropriate references, in our opinion, for each species are listed in appendix 10, illustrated here by table 7 for 11 species selected from life form 7. If the user, after consulting the sources suggested, still does not have sufficient information, the literature cited sections of these sources may provide useful leads.

Versatility Index

Each wildlife species exhibits a different degree of versatility (adaptability) in the number of plant communities and structural conditions it can use for feeding and reproduction. The sensitivity of each species to habitat change is directly related to that versatility. The most versatile species are the least sensitive to habitat manipulation; the least versatile are the most sensitive.

Data in appendices 6 and 7 (illustrated by tables 4 and 5) were used to develop a versatility score (V score) for each species. The V scores can be used to rate the versatility of individual species. Collectively, the scores also provide an index to the relative versatility of all resident wildlife species. Remember, the versatility index is meaningful only for the particular area and conditions for which it is derived. Do not try to make comparisons between different areas and conditions; i.e., do not compare the indices derived for the Blue Mountains of Oregon (Thomas et al. 1979) to those derived for the Great Basin of southeastern Oregon.

The V score for each species is derived by determining the total number of plant communities and the total number of structural conditions to which the species show primary orientation for feeding and reproduction:

$$V = (C_r + S_r) + (C_f + S_f);$$

where V is the versatility score, C_r is the number of communities used by the species for reproduction, S_r is the number of structural conditions used for reproduction, C_f is the number of communities used for feeding, and S_f is the number of structural conditions used for feeding.

Table 7—Selected references for species in life form 7 (source: appendix 10)

Common name	References
Green heron	Kushlan 1976
Black-crowned night heron	Allen and Mangels 1938-39, Hoffman and Prince 1975, Nickell 1966, Wolford and Boag 1971
Swainson's hawk	Dunkle 1977, Fitzner 1978, Olendorff 1972
Calliope hummingbird	Calder 1971, 1973
Eastern kingbird	Dick and Rising 1965, Hespenheide 1964, Morehouse and Brewer 1968
Willow flycatcher	Aldrich 1955, King 1955, Robbins 1974
Gray flycatcher	Johnson 1963, Lavers 1975, Russell and Woodbury 1941
Black-billed magpie	Bock and Lepthien 1975, Brown 1957, Erpino 1968, Jones 1960
American robin	Farner 1949, Henny 1972, James and Shugart 1974
Brewer's blackbird	Hansen and Carter 1963, Horn 1968, Stepney 1975, Williams 1952
Brown-headed cowbird	Friedmann 1963, Hill 1976, Payne 1976

V scores for all wildlife species in the Great Basin of southeastern Oregon are shown in appendix 11 and illustrated here by table 8. The V score for each species can be used to derive a V score for the life form as a whole as illustrated in table 9 and shown for all life forms in appendix 12. These scores reflect the versatility of species only in the Great Basin of southeastern Oregon. It is possible for a nationally common and very versatile species to have a low V score in a particular area because suitable habitat is limited.

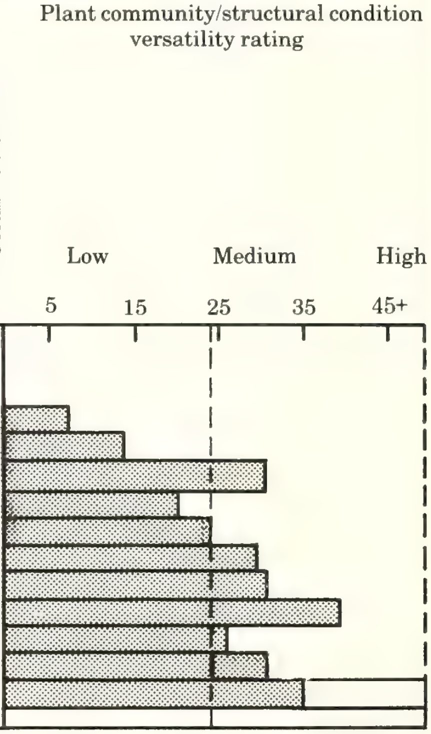
Potentially rare or threatened species are identified in appendix 13 (illustrated by table 10). These species were identified by Dyrness et al. (1975), Arbib (1978), and the U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife (1973) among others. More complete data on rare, threatened, and endangered species are given in appendix 13.

A Data Base For Planners

The informational displays presented here are a data base from which the rangeland manager may draw information at various levels. The system has been tested in preparation of land-use plans, environmental impact statements, and environmental analysis reports. It has enabled the users to produce better, more comprehensive, and more accurate results in less time.

Table 8— Versatility rating for wildlife species in life form 7 (source: appendix 11)

		Reproductive orientation			Feeding orientation			
Letter code	Species	No. of plant communities used (1)	No. of structural conditions used (2)	Columns 1 & 2 (3)	No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score Columns 3 & 6 (7)
	BIRDS							
BUST	green heron	1	3	4	1	4	5	9
NYNY	black-crowned night heron	3	3	6	5	3	8	14
BUSW	Swainson's hawk	5	6	11	10	10	20	31
STCAL	calliope hummingbird	5	3	8	7	5	12	20
TYTY	eastern kingbird	6	3	9	8	7	15	24
EMTR	willow flycatcher	3	6	9	12	8	20	29
EMWR	gray flycatcher	7	6	13	12	6	18	31
PIPI	black-billed magpie	9	6	15	15	10	25	40
TUMI	American robin	3	6	9	9	8	17	26
EUCY	Brewer's blackbird	7	15	12	14	5	19	31
MOAT	brown-headed cowbird	7	7	14	14	7	21	35



The information system presented in this chapter is best suited for use in broad-scale land-use planning. The smaller the area and the greater the detail of the plan, the less likely these data are to predict results accurately. The general predictive ability should hold, but the inherent biological variability is more apt to become noticeable as size of the area diminishes.

If this information base is applied without proper interpretation, qualification, and sensitivity to individual conditions, the results will be less accurate. It is not intended to replace the trained and experienced wildlife biologist; rather, it is a tool for use by the wildlife biologist.

Table 9—Life form versatility rating for life form 7 (source: appendix 12)

Life form[1]	Number of species[2]	Range of versatility scores[3]	Mean versatility score	Life form versatility rating[4] (median scale)
7	29	9 to 40 (29)	24.5	High

[1] See table 1 for life form descriptions.

[2] The total number of species in life form.

[3] Refers to the range of versatility scores for the lowest scoring species to the highest scoring species within the life form.

[4] Versatility ratings: "low" = 12.0-17.6, "medium" = 17.7-23.4, "high" = 23.5-29.0.

Table 10—Some species in southeastern Oregon are of special interest because of their potentially threatened or endangered status (source: appendix 13)

		Species	1	2	3	4	5	6	7	8
CRCO	4	collared lizard					X			
CRVI	5	western rattlesnake				SI	X			
NYNY	7	black-crowned night heron						X		
BOLE	3	American bittern				SI		X		
SOPR	16	Malheur shrew				R	R			
VUMA	15	kit fox		T	T	T	E			
Letter code	Life form	E – Endangered P – Peripheral R – Rare SI – Species of special interest SU – Status undetermined T – Threatened U – Unique X – Occurs on list	Federal register (endangered)	Oregon State (endangered or threatened)	U.S. Dep. Inter. Fish & Wildl. Serv. "Red Book"	USDA FS RNA "Yellow Book"	OSU endangered plants and animals of Oregon	Audubon – Blue list for 1979		
			1	2	3	4	5	6	7	8
				(a)[1]			(a,b,c)[1]			

[1] The following references were used, respectively, as sources for the 6 status classification columns.

1 U.S. Fish and Wildlife Service (1979)
2a Oregon Department of Fish and Wildlife (1977)
2b Shay (1973)
3 U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife (1973)
4 Dyrness et al. (1975)
5a Storm (1966)
5b Marshall (1969)
5c Olterman and Verts (1972)
6 Arbib (1978)

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WILDLIFE HABITATS IN MANAGED RANGELANDS—THE GREAT BASIN OF SOUTHEASTERN OREGON

Technical Editors

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GENERAL TECHNICAL REPORT PNW-172
PART 2 OF 2 1984

WILDLIFE HABITATS IN MANAGED RANGELANDS-- THE GREAT BASINS OF SOUTHEASTERN OREGON

THE RELATIONSHIP OF TERRESTRIAL VERTEBRATES TO PLANT COMMUNITIES AND STRUCTURAL CONDITIONS

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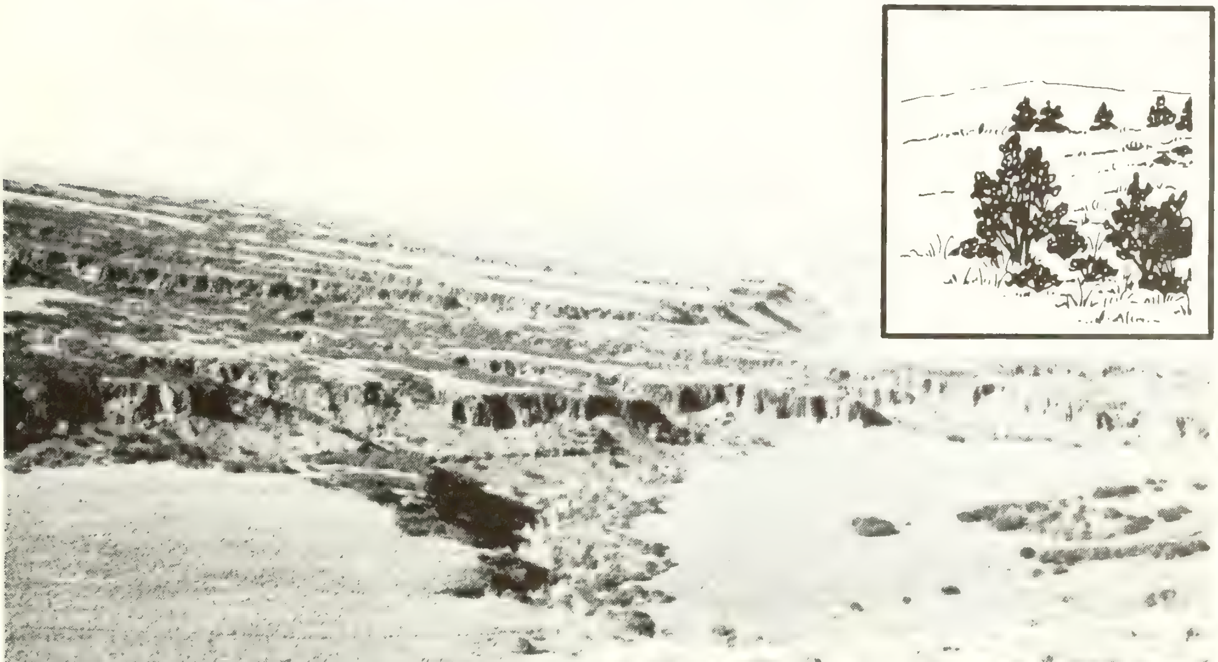

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

ABSTRACT

The relationships of terrestrial vertebrates to plant communities, structural conditions, and special habitats in the Great Basin of southeastern Oregon are described in a series of appendices. The importance of habitat components to wildlife and the predictability of management activities on wildlife are examined in terms of managed rangelands. The derivation and use of these appendices are described in a companion publication, General Technical Report PNW-172, Part 1.

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This publication is part of the series **Wildlife Habitats in Managed Rangelands—The Great Basin of Southeastern Oregon.** The purpose of the series is to provide a range manager with the necessary information on wildlife and its relationship to habitat conditions in managed rangelands in order that the manager may make fully informed decisions.

The information in this series is specific to the Great Basin of southeastern Oregon and is generally applicable to the shrub-steppe areas of the Western United States. The principles and processes described, however, are generally applicable to all managed rangelands. The purpose of the series is to provide specific information for a particular area but in doing so to develop a process for considering the welfare of wildlife when range management decisions are made.

The series is composed of 14 separate publications designed to form a comprehensive whole. Although each part will be an independent treatment of a specific subject, when combined in sequence, the individual parts will be as chapters in a book.

Individual parts will be printed as they become available. In this way the information will be more quickly available to potential users. This means, however, that the sequence of printing will not be in the same order as the final organization of the separates into a comprehensive whole.

A list of the publications in the series, their current availability, and their final organization is shown on the inside back cover of this publication.

Wildlife Habitats in Managed Rangelands—The Great Basin of Southeastern Oregon is a cooperative effort of the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, and United States Department of the Interior, Bureau of Land Management.

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Introduction

The appendices that follow provide the data base information to consider wildlife habitat relationships in that portion of the Great Basin that lies in southeastern Oregon. The details on how this information was derived and how it may be used to analyze impacts of land management decisions on terrestrial vertebrates are given in:

> Maser, Chris; Thomas, Jack Ward; Anderson, Ralph G. Wildlife habitats in managed rangelands—the Great Basin of southeastern Oregon: the relationships of terrestrial vertebrates to plant communities and structural conditions. Gen. Tech. Rep. PNW-172, part 1 of 2 parts. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1984. 25 p.

These appendices are published separately as they are apt to be of interest primarily to those applying the wildlife habitat relationships system to the particular geographical area described. The text (part 1, referenced above) discusses the principles and procedures concerning the development and application of wildlife habitat relationships that are of a more general interest.

Appendix 1. 341 wildlife species of southeast Oregon listed phylogenetically by common and scientific names.

Letter code	Life form	Common name	Scientific name
		AMPHIBIANS	
AMMA	2	long-toed salamander	*Ambystoma macrodactylum*
SCIN	2	Great Basin spadefoot	*Scaphiopus intermontanus*
BUBO	2	western toad	*Bufo boreas*
BUWO	2	Woodhouse toad	*Bufo woodhousei*
HYRE	2	Pacific treefrog	*Hyla regilla*
RAPR	1	spotted frog	*Rana pretiosa*
RAPI	2	leopard frog	*Rana pipiens*
RACA	1	bullfrog	*Rana catesbiana*
		REPTILES	
CRCO	4	collared lizard	*Crotaphytus collaris*
CRWI	5	leopard lizard	*Crotaphytus wislizeni*
SCOC	4	western fence lizard	*Sceloporus occidentalis*
SCGR	5	sagebrush lizard	*Sceloporus graciosus*
UTST	5	side-blotched lizard	*Uta stansburiana*
PHPL	5	desert horned lizard	*Phrynosoma platyrhinos*
PHDO	5	short-horned lizard	*Phrynosoma douglassi*
EUSK	5	western skink	*Eumeces skiltonianus*
CNTI	5	western whiptail	*Cnemidophorus tigris*
CHBO	5	rubber boa	*Charina bottae*
COCONS	5	yellow-bellied racer	*Coluber constrictor*
MATA	5	striped whipsnake	*Masticophis taeniatus*
PIME	5	gopher snake	*Pituophis melanoleucus*
THSI	3	common garter snake	*Thamnophis sirtalis*
THEL	3	wandering garter snake	*Thamnophis elegans*
SOSE	15	western ground snake	*Sonora semiannulata*
HYTO	5	night snake	*Hypsiglena torquata*
CRVI	5	western rattlesnake	*Crotalus viridis*

Letter code	Life form	Common name	Scientific name
		BIRDS	
GAIM	3	common loon	*Gavia immer*
POGRI	3	red-necked grebe	*Podiceps grisegena*
POAU	3	horned grebe	*Podiceps auritus*
PONIGR	3	eared grebe	*Podiceps nigricollis*
AEOC	3	western grebe	*Aechmophorus occidentalis*
POPO	3	pied-billed grebe	*Podilymbus podiceps*
PEERY	3	American white pelican	*Pelecanus erythrorhynchos*
PHAU	3	double-crested cormorant	*Phalacrocorax auritus*
ARHE	12	great blue heron	*Ardea herodias*
BUST	7	green heron	*Butorides striatus*
CAAL	12	common egret	*Casmerodius albus*
BUIB	7	cattle egret	*Bubuculus ibis*
NYNY	7	black-crowned night heron	*Nycticorax nycticorax*
BOLE	3	American bittern	*Botaurus lentiginosus*
IXEX	3	least bittern	*Ixobrychus exilis*
PLCH	7	white-faced ibis	*Plegadis chihi*
OLCO	3	whistling swan	*Olor columbianus*
BRCA	3	Canada goose	*Branta canadensis*
BRCALE	3	Aleutian Canada goose	*Branta canadensis leucopareia*
ANAL	3	greater white-fronted goose	*Anser albifrons*
ANALGA	3	Tule white-fronted goose	*Anser albifrons gambelli*
CHCA	3	snow goose	*Chen caerulescens*
CHRO	3	Ross' goose	*Chen rossii*
ANPL	3	mallard	*Anas platyrhynchos*
ANSTR	3	gadwall	*Anas strepera*
ANAC	3	common pintail	*Anas acuta*
ANCR	3	green-winged teal	*Anas crecca*
ANDIS	3	blue-winged teal	*Anas discors*
ANCY	3	cinnamon teal	*Anas cyanoptera*
ANAMEO	3	American wigeon	*Anas americana*
ANCL	3	northern shoveler	*Anas clypeata*
AISP	14	wood duck	*Aix sponsa*
AYAM	3	redhead	*Aythya americana*
AYCO	3	ring-necked duck	*Aythya collaris*
AYVA	3	canvasback	*Aythya valisineria*
AYMA	3	greater scaup	*Aythya marila*
AYAF	3	lesser scaup	*Aythya affinis*
BUCL	3	common goldeneye	*Bucephala clangula*
BUIS	14	Barrow's goldeneye	*Bucephala islandica*
BUALBE	14	bufflehead	*Bucephala albeola*
SOSP	3	king eider	*Somateria spectabilis*
CLHY	3	oldsquaw	*Clangula hyemalis*
OXJA	3	ruddy duck	*Oxyura jamaicensis*
LOCU	14	hooded merganser	*Lophodytes cucullatus*
MEMER	14	common merganser	*Mergus merganser*
MESE	3	red-breasted merganser	*Mergus serrator*
CAAU	4	turkey vulture	*Cathartes aura*
ACGE	11	northern goshawk	*Accipiter gentilis*
ACST	11	sharp-shinned hawk	*Accipiter striatus*
ACCO	11	Cooper's hawk	*Accipiter cooperii*
BUJA	12	red-tailed hawk	*Buteo jamaicensis*
BUSW	7	Swainson's hawk	*Buteo swainsoni*
BULA	4	rough-legged hawk	*Buteo lagopus*
BUREG	4	ferruginous hawk	*Buteo regalis*
AQCH	12	golden eagle	*Aquila chrysaetos*
HALE	12	bald eagle	*Haliaeetus leucocephalus*
CICY	5	northern harrier	*Circus cyaneus*
PAHA	12	osprey	*Pandion haliaetus*
FAME	4	prairie falcon	*Falco mexicanus*
FAPE	4	peregrine	*Falco peregrinus*
FACO	11	merlin	*Falco columbarius*
FASP	14	American kestrel	*Falco sparverius*
DEOB	5	blue grouse	*Dendragapus obscurus*
BOUM	5	ruffed grouse	*Bonasa umbellus*
CEUR	5	sage grouse	*Centrocercus urophasianus*
LOCA	5	California quail	*Lophortyx californicus*
ORPI	5	mountain quail	*Oreortyx pictus*
ALCH	4	chukar	*Alectoris chukar*
PEPER	5	grey partridge	*Perdix perdix*
PHCOL	5	ring-necked pheasant	*Phasianus colchicus*
GRCA	3	sandhill crane	*Grus canadensis*

Letter code	Life form	Common name	Scientific name
RALI	3	Virginia rail	*Rallus limicola*
POCAR	3	sora	*Porzana carolina*
FUAM	3	American coot	*Fulica americana*
CHSEM	3	semipalmated plover	*Charadrius semipalmatus*
CHALE	3	snowy plover	*Charadrius alexandrinus*
CHVO	3	killdeer	*Charadrius vociferus*
CHMO	3	mountain plover	*Charadrius montanus*
CAGA	3	common snipe	*Capella gallinago*
NUAM	3	long-billed curlew	*Numenius americanus*
ACMA	3	spotted sandpiper	*Actitis macularia*
TRSO	7	solitary sandpiper	*Tringa solitaria*
TRME	3	greater yellowlegs	*Tringa melanoleuca*
TRFL	3	lesser yellowlegs	*Tringa flavipes*
CASE	3	willet	*Catoptrophorus semipalmatus*
CAMEL	3	pectoral sandpiper	*Calidris melanotos*
CABA	3	Baird's sandpiper	*Calidris bairdii*
CAMI	3	least sandpiper	*Calidris minutilla*
CAMAU	3	western sandpiper	*Calidris mauri*
LISC	3	long-billed dowitcher	*Limodromus scolopaceus*
LIFE	3	marbled godwit	*Limosa fedoa*
REAM	3	American avocet	*Recurvirostra americana*
HIME	3	black-necked stilt	*Himantopus mexicanus*
STTRI	3	Wilson's phalarope	*Steganopus tricolor*
LOLO	3	nothern phalarope	*Lobipes lobatus*
LAAR	3	herring gull	*Larus argentatus*
LACA	3	California gull	*Larus californicus*
LADE	3	ring-billed gull	*Larus delawarensis*
LAPI	3	Franklin's gull	*Larus pipixcan*
LAPH	3	Bonaparte's gull	*Larus philadelphia*
STFO	3	Forster's tern	*Sterna forsteri*
STCAS	3	Caspian tern	*Sterna caspia*
CHNI	3	black tern	*Chlidonias niger*
COLI	4	rockdove	*Columba livia*
ZEMA	11	mourning dove	*Zenaida macroura*
COAM	8	yellow-billed cuckoo	*Coccyzus americanus*
TYAL	14	barn owl	*Tyto alba*
OTAS	14	common screech owl	*Otus asio*
OTFL	14	flammulated owl	*Otus flammeolus*
BUVIR	12	great horned owl	*Bubo virginianus*
GLGN	14	pygmy owl	*Glaucidium gnoma*
ATCU	15	burrowing owl	*Athene cunicularia*
ASOT	11	long-eared owl	*Asio otus*
ASFL	5	short-eared owl	*Asio flammeus*
AEAC	14	saw-whet owl	*Aegolius acadicus*
PHNU	6	poorwill	*Phalaenoptilus nuttalli*
CHMI	6	common nighthawk	*Chordeiles minor*
CYNI	4	black swift	*Cypseloides niger*
CHVA	14	Vaux's swift	*Chaetura vauxi*
AESA	4	white-throated swift	*Aeronautes saxatalis*
ARAL	7	black-chinned hummingbird	*Archilochus alexandri*
SEPL	7	broad-tailed hummingbird	*Selasphorus platycercus*
SERUF	11	rufous hummingbird	*Selasphorus rufus*
STCAL	7	calliope hummingbird	*Stellula calliope*
CAAN	7	Anna's hummingbird	*Calypte anna*
MEAL	16	belted kingfisher	*Megaceryle alcyon*
COAU	13	common flicker	*Colaptes auratus*
MELE	13	Lewis' woodpecker	*Melanerpes lewis*
SPVAR	13	yellow-bellied sapsucker	*Sphyrapicus varius*
SPTH	13	Williamson's sapsucker	*Sphyrapicus thyroideus*
PIVI	13	hairy woodpecker	*Picoides villosus*
PIPU	13	downy woodpecker	*Picoides pubescens*
PIAL	13	white-headed woodpecker	*Picoides albolarvatus*
TYTY	7	eastern kingbird	*Tyrannus tyrannus*
TYVE	11	western kingbird	*Tyrannus verticalis*
MYCI	14	ash-throated flycatcher	*Myiarchus cinerascens*
SASA	4	Say's phoebe	*Sayornis saya*
EMTR	7	willow flycatcher	*Empidonax traillii*
EMHA	11	Hammond's flycatcher	*Empidonax hammondii*

Letter code	Life form	Common name	Scientific name
EMWR	7	gray flycatcher	*Empidonax wrightii*
EMDI	10	western flycatcher	*Empidonax difficilis*
COSO	11	western wood pewee	*Contopus sordidulus*
NUBO	10	olive-sided flycatcher	*Nuttallornis borealis*
ERAL	5	horned lark	*Eremophila alpestris*
TATH	14	violet-green swallow	*Tachycineta thalassina*
IRBI	14	tree swallow	*Iridoprocne bicolor*
RIRI	16	bankswallow	*Riparia riparia*
STRU	16	rough-winged swallow	*Stelgidopteryx ruficollis*
HIRU	4	barn swallow	*Hirundo rustica*
PEPY	4	cliff swallow	*Petrochelidon pyrrhonota*
PECA	11	gray jay	*Perisoreus canadensis*
CYST	11	Steller's jay	*Cyanocitta stelleri*
APCO	7	scrub jay	*Aphelocoma coerulescens*
PIPI	7	black-billed magpie	*Pica pica*
COCOR	4	northern raven	*Corvus corax*
COBRA	11	American crow	*Corvus brachyrhynchos*
GYCY	10	pinyon jay	*Gymnorhinus cyanocephalus*
NUCO	10	Clark's nutcracker	*Nucifraga columbiana*
PAATR	14	black-capped chickadee	*Parus atricapillus*
PAGA	14	mountain chickadee	*Parus gambeli*
PSMI	8	bushtit	*Psaltriparus minimus*
SICAR	13	white-breasted nuthatch	*Sitta carolinensis*
SICAN	13	red-breasted nuthatch	*Sitta canadensis*
CEFA	14	brown creeper	*Certhia familiaris*
CIME	3	dipper	*Cinclus mexicanus*
TRAE	14	house wren	*Troglodytes aedon*
TRTR	3	winter wren	*Troglodytes troglodytes*
CIPA	3	marsh wren	*Cistophorus palustris*

Letter code	Life form	Common name	Scientific name
CAMEXO	4	canyon wren	*Catherpes mexicanus*
SAOB	4	rock wren	*Salpinctes obsoletus*
MIPO	7	northern mockingbird	*Mimus polyglottos*
DUCA	7	gray catbird	*Dumetella carolinensis*
TORU	7	brown thrasher	*Toxostoma rufum*
ORMO	7	sage thrasher	*Oreoscoptes montanus*
TUMI	7	American robin	*Turdus migratorius*
IXNA	11	varied thrush	*Ixoreus naevius*
CAGU	5	hermit thrush	*Catharus guttatus*
CAUS	7	Swainson's thrush	*Catharus ustulatus*
CAFU	5	veery	*Catharus fuscescens*
SIME	14	western bluebird	*Sialia mexicana*
SICU	14	mountain bluebird	*Sialia currucoides*
MYTO	6	Townsend's solitaire	*Myadestes townsendi*
POCAE	7	blue-gray gnatcatcher	*Polioptila caerulea*
RESA	10	golden-crowned kinglet	*Regulus satrapa*
RECA	10	ruby-crowned kinglet	*Regulus calendula*
ANSP	5	water pipit	*Anthus spinoletta*
BOGA	9	Bohemian waxwing	*Bombycilla garrulus*
BOCE	9	cedar waxwing	*Bombycilla cedrorum*
LAEX	7	northern shrike	*Lanius excubitor*
LALU	7	loggerhead shrike	*Lanius ludovicianus*
STVU	14	European starling	*Sturnus vulgaris*
VISO	11	solitary vireo	*Vireo solitarius*
VIOL	11	red-eyed vireo	*Vireo olivaceus*
VIGI	11	warbling vireo	*Vireo gilvus*
VECE	6	orange-crowned warbler	*Vermivora celata*
DEPE	8	yellow warbler	*Dendroica petechia*
DECOR	10	yellow-rumped warbler	*Dendroica coronata*
DENI	10	black-throated grey warbler	*Dendroica nigrescens*

Letter code	Life form	Common name	Scientific name
DETO	10	Townsend's warbler	*Dendroica townsendi*
OPTO	7	MacGillivray's warbler	*Oporornis tolmiei*
GETR	3	common yellowthroat	*Geothlypis trichas*
ICVI	8	yellow-breasted chat	*Icteria virens*
SEAU	7	ovenbird	*Seiurus aurocapillus*
WIPU	5	Wilson's warbler	*Wilsonia pusilla*
SERUT	9	American redstart	*Setophaga ruticilla*
PADO	14	house sparrow	*Passer domesticus*
DOOR	5	bobolink	*Dolichonyx oryzivorus*
STNEG	5	western meadowlark	*Sturnella neglecta*
XAXA	7	yellow-headed blackbird	*Xanthocephalus xanthocephalus*
AGPH	7	red-winged blackbird	*Agelaius phoeniceus*
ICGA	9	northern oriole	*Icterus galbula*
EUCY	7	Brewer's blackbird	*Euphagus cyanocephalus*
MOAT	7	brown-headed cowbird	*Molothrus ater*
PILU	10	western tanager	*Piranga ludoviciana*
PHLU	9	rose-breasted grosbeak	*Pheucticus ludovicianus*
PHME	11	black-headed grosbeak	*Pheucticus melanocephalus*
PACY	8	indigo bunting	*Passerina cyanea*
PAAMO	7	lazuli bunting	*Passerina amoena*
HEVE	11	evening grosbeak	*Hesperiphona vespertina*
CAPU	11	purple finch	*Carpodacus purpureus*
CACUS	11	Cassin's finch	*Carpodacus cassinii*
CAMEXI	9	house finch	*Carpodacus mexicanus*
LEAT	4	black rosy finch	*Leucosticte atrata*
CAFL	9	common redpoll	*Carduelis flammea*
CAPI	11	pine siskin	*Carduelis pinus*
CATR	8	American goldfinch	*Carduelis tristis*
CAPS	7	lesser goldfinch	*Carduelis psaltria*

Letter code	Life form	Common name	Scientific name
PICH	7	green-tailed towhee	*Pipilo chlorura*
PIER	7	rufous-sided towhee	*Pipilo erythrophthalmus*
PASA	5	savannah sparrow	*Passerculus sandwichensis*
AMSA	5	grasshopper sparrow	*Ammodramus savannarum*
POGRA	5	vesper sparrow	*Pooecetes gramineus*
CHGR	5	lark sparrow	*Chondestes grammacus*
AMBI	7	black-throated sparrow	*Amphispiza bilineata*
AMBE	7	sage sparrow	*Amphispiza belli*
JUHY	5	northern junco	*Junco hyemalis*
SPARB	11	American tree sparrow	*Spizella arborea*
SPPA	7	chipping sparrow	*Spizella passerina*
SPBRE	7	Brewer's sparrow	*Spizella breweri*
ZOLE	7	white-crowned sparrow	*Zonotrichia leucophrys*
ZOAT	7	golden-crowned sparrow	*Zonotrichia atricapilla*
PAIL	7	fox sparrow	*Passerella iliaca*
MELI	6	Lincoln's sparrow	*Melospiza lincolnii*
MEMEL	7	song sparrow	*Melospiza melodia*
CALA	5	Lapland longspur	*Calcarius lapponicus*
PLNI	5	snow bunting	*Plectophenax nivalis*
		MAMMALS	
SOPR	16	Malheur shrew	*Sorex preblei*
SOVA	16	wandering shrew	*Sorex vagrans*
SOME	15	Merriam shrew	*Sorex merriami*
MYLU	4	little brown myotis	*Myotis lucifugus*
MYYU	14	Yuma myotis	*Myotis yumanensis*
MYEV	14	long-eared myotis	*Myotis evotis*
MYTH	4	fringed myotis	*Myotis thysanodes*
MYVO	14	long-legged myotis	*Myotis volans*
MYCA	4	California myotis	*Myotis californicus*
MYLE	4	small-footed myotis	*Myotis leibi*

Letter code	Life form	Common name	Scientific name
LANO	14	silver-haired bat	*Lasionycteris noctivagans*
PIHE	4	western pipistrelle	*Pipistrellus hesperus*
EPFU	4	big brown bat	*Eptesicus fuscus*
LACI	9	hoary bat	*Lasiurus cinereus*
EUMAC	4	spotted bat	*Euderma maculatum*
PLTO	4	western big-eared bat	*Plecotus townsendi*
ANPA	4	pallid bat	*Antrozous pallidus*
SYID	5	pygmy rabbit	*Sylvilagus idahoensis*
SYNU	5	mountain cottontail	*Sylvilagus nuttalli*
LETO	5	white-tailed jackrabbit	*Lepus townsendi*
LECA	5	black-tailed jackrabbit	*Lepus californicus*
EUMI	15	least chipmunk	*Eutamias minimus*
EUAM	15	yellow pine chipmunk	*Eutamias amoenus*
MAFL	4	yellow-bellied marmot	*Marmota flaviventris*
AMLE	15	antelope ground squirrel	*Ammospermophilus leucurus*
SPTO	15	Townsend ground squirrel	*Spermophilus townsendi*
SPRI	15	Richardson ground squirrel	*Spermophilus richardsoni*
SPBE	15	Belding ground squirrel	*Spermophilus beldingi*
SPCO	15	Columbian ground squirrel	*Spermophilus columbianus*
SPLA	15	mantled ground squirrel	*Spermophilus lateralis*
THTO	15	Townsend pocket gopher	*Thomomys townsendi*
THTA	15	northern pocket gopher	*Thomomys talpoides*
PELO	15	little pocket mouse	*Perognathus longimembris*
PEPA	15	Great Basin pocket mouse	*Perognathus parvus*
MIME	15	dark kangaroo mouse	*Microdipodops megacephalus*
DIOR	15	Ord kangaroo rat	*Dipodomys ordi*
DIMI	15	chisel-toothed kangaroo rat	*Dipodomys microps*
CACAN	16	beaver	*Castor canadensis*
REME	15	western harvest mouse	*Reithrodontomys megalotis*
PECR	4	canyon mouse	*Peromyscus crinitus*
PEMA	15	deer mouse	*Peromyscus maniculatus*
ONLE	15	northern grasshopper mouse	*Onychomys leucogastor*
NELE	4	desert woodrat	*Neotoma lepida*
NECI	4	bushy-tailed woodrat	*Neotoma cinerea*
MIMO	15	montane vole	*Microtus montanus*
MILO	15	long-tailed vole	*Microtus longicaudus*
LACU	15	sage vole	*Lagurus curtatus*
ONZI	16	muskrat	*Ondatra zibethicus*
RARA	5	black rat	*Rattus rattus*
RANO	5	Norway rat	*Rattus norvegicus*
ZAPR	15	western jumping mouse	*Zapus princeps*
ERDO	4	porcupine	*Erethizon dorsatum*
CALAT	15	coyote	*Canis latrans*
VUVU	15	red fox	*Vulpes vulpes*
VUMA	15	kit fox	*Vulpes macrotis*
PRLO	14	raccoon	*Procyon lotor*
MUER	15	short-tailed weasel	*Mustela erminea*
MUFR	15	long-tailed weasel	*Mustela frenata*
MUVI	16	mink	*Mustela vison*
TATA	15	badger	*Taxidea taxus*
SPPU	4	spotted skunk	*Spilogale putorius*
MEMEP	15	stripped skunk	*Mephitis mephitis*
LUCA	16	river otter	*Lutra canadensis*
FECO	4	puma	*Felis concolor*
FECA	5	feral house cat	*Felis catus*
LYRU	4	bobcat	*Lynx rufus*
EQCA	5	feral horse	*Equus cabalus*
CEEL	5	elk	*Cervus elaphus*
ODHE	5	mule deer	*Odocoileus hemionus*
ANAMER	5	pronghorn	*Antilocapra americana*
OVCA	5	bighorn sheep	*Ovis canadensis*

Appendix 2. Alphabetical computer codes for 341 wildlife species in southeast Oregon.

Letter code	Life form	Scientific name	Common name
ACCO	11	*Accipiter cooperii*	Cooper's hawk
ACGE	11	*Accipiter gentilis*	northern goshawk
ACMA	3	*Actitis macularia*	spotted sandpiper
ACST	11	*Accipiter striatus*	sharp-shinned hawk
AEAC	14	*Aegolius acadicus*	saw-whet owl
AEOC	3	*Aechmophorus occidentalis*	western grebe
AESA	4	*Aeronautes saxitalis*	white-throated swift
AGPH	7	*Agelaius phoeniceus*	red-winged blackbird
AISP	14	*Aix sponsa*	wood duck
ALCH	4	*Alectoris chukar*	chukar
AMBE	7	*Amphispiza belli*	sage sparrow
AMBI	7	*Amphispiza bilineata*	black-throated sparrow
AMLE	15	*Ammospermophilus leucurus*	antelope ground squirrel
AMMA	2	*Ambystoma macrodactylum*	long-toed salamander
AMSA	5	*Ammodramus savannarum*	grasshopper sparrow
ANAC	3	*Anas acuta*	common pintail
ANAL	3	*Anser albifrons*	greater white-fronted goose
ANALGA	3	*Anser albifrons gambelli*	Tule white-fronted goose
ANAMEO	3	*Anas americana*	American wigeon
ANAMER	5	*Antilocapra americana*	pronghorn
ANCL	3	*Anas clypeata*	northern shoveler
ANCR	3	*Anas crecca*	green-winged teal
ANCY	3	*Anas cyanoptera*	cinnamon teal
ANDIS	3	*Anas discors*	blue-winged teal
ANPA	4	*Antrozous pallidus*	pallid bat
ANPL	3	*Anas platyrhynchos*	mallard
ANSP	5	*Anthus spinoletta*	water pipit
ANSTR	3	*Anas strepera*	gadwall
APCO	7	*Aphelocoma coerulescens*	scrub jay
AQCH	12	*Aquila chrysaetos*	golden eagle
ARAL	7	*Archilochus alexandri*	black-chinned hummingbird
ARHE	12	*Ardea herodias*	great blue heron
ASFL	15	*Asio flammeus*	short-eared owl
ASOT	11	*Asio otus*	long-eared owl
ATCU	15	*Athene cunicularia*	burrowing owl
AYAF	3	*Aythya affinis*	lesser scaup
AYAM	3	*Aythya americana*	redhead
AYCO	3	*Aythya collaris*	ring-necked duck
AYMA	3	*Aythya marila*	greater scaup
AYVA	3	*Aythya valisineria*	canvasback
BOCE	9	*Bombycilla cedrorum*	cedar waxwing
BOGA	9	*Bombycilla garrulus*	Bohemian waxwing
BOLE	3	*Botaurus lentiginosus*	American bittern
BOUM	5	*Bonasa umbellus*	ruffed grouse
BRCA	3	*Branta canadensis*	Canada goose
BRCALE	3	*Branta canadensis gambelli*	Aleutian Canada goose
BUALBE	14	*Bucephala albeola*	bufflehead
BUBO	2	*Bufo boreas*	western toad
BUCL	3	*Bucephala clangula*	common goldeneye
BUIB	7	*Bubuculus ibis*	cattle egret
BUIS	14	*Bucephala islandica*	Barrow's goldeneye
BUJA	12	*Buteo jamaicensis*	red-tailed hawk
BULA	4	*Buteo lagopus*	rough-legged hawk
BUREG	4	*Buteo regalis*	ferruginous hawk
BUST	7	*Butorides striatus*	green heron
BUSW	7	*Buteo swainsoni*	Swainson's hawk
BUVIR	12	*Bubo virginianus*	great horned owl
BUWO	2	*Bufo woodhousei*	Woodhouse toad
CAAL	12	*Casmerodius albus*	common egret
CAAN	7	*Calypte anna*	Anna's hummingbird
CAAU	4	*Cathartes aura*	turkey vulture
CABA	3	*Calidris bairdii*	Baird's sandpiper
CACAN	16	*Castor canadensis*	beaver
CACAS	11	*Carpodacus cassinii*	Cassin's finch
CAFL	9	*Carduelis flammea*	common redpoll
CAFU	5	*Catharus fuscescens*	veery
CAGA	3	*Capella gallinago*	common snipe
CAGU	5	*Catharus guttatus*	hermit thrush
CALA	5	*Calcarius lapponicus*	Lapland longspur

Letter code	Life form	Scientific name	Common name
CALAT	15	*Canis latrans*	coyote
CAMAU	3	*Calidris mauri*	western sandpiper
CAMEL	3	*Calidris melanots*	pectoral sandpiper
CAMEXO	4	*Catherpes mexicanus*	canyon wren
CAMEXI	9	*Carpodacus mexicanus*	house finch
CAMI	3	*Calidris minutilla*	least sandpiper
CAPI	11	*Carduelis pinus*	pine siskin
CAPS	7	*Carduelis psaltria*	lesser goldfinch
CAPU	11	*Carpodacus purpureus*	purple finch
CASE	3	*Catoptrophorus semipalmatus*	willet
CATR	8	*Carduelis tristis*	American goldfinch
CAUS	7	*Catharus ustulatus*	Swainson's thrush
CEEL	5	*Cervus elaphus*	elk
CEFA	14	*Certhia familiaris*	brown creeper
CEUR	5	*Centrocercus urophasianus*	sage grouse
CHALE	3	*Charadrius alexandrius*	snowy plover
CHBO	5	*Charina bottae*	rubber boa
CHCA	3	*Chen caerulescens*	snow goose
CHGR	5	*Chondestes grammacus*	lark sparrow
CHMI	6	*Chordeiles minor*	common nighthawk
CHMO	3	*Charadrius montanus*	mountain plover
CHNI	3	*Chlidonias niger*	black tern
CHRO	3	*Chen rossii*	Ross' goose
CHSEM	3	*Charadrius semipalmatus*	semipalmated plover
CHVA	14	*Chaetura vauxi*	Vaux's swift
CHVO	3	*Charadrius vociferus*	killdeer
CICY	5	*Circus cyaneus*	northern harrier
CIME	3	*Cinclus mexicanus*	dipper
CIPA	3	*Cistophorus palustris*	marsh wren
CLHY	3	*Clangula hyemalis*	oldsquaw
CNTI	5	*Cnemidophorus tigris*	western whiptail
COAM	8	*Coccyzus americanus*	yellow-billed cuckoo
COAU	13	*Colaptes auratus*	common flicker
COBRA	11	*Corvus brachyrhynchos*	American crow
COCONS	5	*Coluber constrictor*	yellow-bellied racer
COCOR	4	*Corvus corax*	northern raven
COLI	4	*Columba livia*	rock dove
COSO	11	*Contopus sordidulus*	western wood pewee
CRCO	4	*Crotaphytus collaris*	collared lizard
CRVI	5	*Crotalis viridis*	western rattlesnake
CRWI	5	*Crotaphytus wislizeni*	leopard lizard
CYNI	4	*Cypseloides niger*	black swift
CYST	11	*Cyanocitta stelleri*	Steller's jay
DECOR	10	*Dendroica coronata*	yellow-rumped warbler
DENI	10	*Dendroica nigrescens*	black-throated grey warbler
DEOB	5	*Dendragapus obscurus*	blue grouse
DEPE	8	*Dendroica petechia*	yellow warbler
DETO	10	*Dendroica townsendi*	Townsend's warbler
DIMI	15	*Dipodomys microps*	chisel-toothed kangaroo rat
DIOR	15	*Dipodomys ordi*	Ord kangaroo rat
DOOR	5	*Dolichonyx oryzivorus*	bobolink
DUCA	7	*Dumetella carolinensis*	gray catbird
EMDI	10	*Empidonax difficilis*	western flycatcher
EMHA	11	*Empidonax hammondii*	Hammond's flycatcher
EMTR	7	*Empidonax traillii*	willow flycatcher
EMWR	7	*Empidonax wrightii*	gray flycatcher
EPFU	4	*Eptesicus fuscus*	big brown bat
EQCA	5	*Equus cabalus*	feral horse
ERAL	5	*Eremophila alpestris*	horned lark
ERDO	4	*Erethizon dorsatum*	porcupine
EUAM	15	*Eutamias amoenus*	yellow pine chipmunk
EUCY	7	*Euphagus cyanocephalus*	Brewer's blackbird

Letter code	Life form	Scientific name	Common name
EUMA	4	*Euderma maculatum*	spotted bat
EUMI	15	*Eutamias minimus*	least chipmunk
EUSK	5	*Eumeces skiltonianus*	western skink
FACO	11	*Falco columbarius*	merlin
FAME	4	*Falco mexicanus*	prairie falcon
FAPE	4	*Falco peregrinus*	peregrine falcon
FASP	14	*Falco sparverius*	American kestrel
FECA	5	*Felis catus*	feral house cat
FECO	4	*Felis concolor*	puma
FUAM	3	*Fulica ameriana*	American coot
GAIM	3	*Gavia immer*	common loon
GETR	3	*Geothlypis trichas*	common yellowthroat
GLGN	14	*Glaucidium gnoma*	pygmy owl
GRCA	3	*Grus canadensis*	sandhill crane
GYCY	10	*Gymnorhinus cyanocephalus*	pinyon jay
HALE	12	*Haliaeetus leucocephalus*	baldeagle
HEVE	11	*Hesperiphona vespertina*	evening grosbeak
HIME	3	*Himantopus mexicanus*	black-necked stilt
HIRU	4	*Hirundo rustica*	barn swallow
HYRE	2	*Hyla regilla*	Pacific treefrog
HYTO	5	*Hypsiglena torquata*	night snake
ICGA	9	*Icterus galbula*	northern oriole
ICVI	8	*Icteria virens*	yellow-breasted chat
IRBI	14	*Iridoprocne bicolor*	tree swallow
IXEX	3	*Ixobrychus exilis*	least bittern
IXNA	11	*Ixoreus naevius*	varied thrush
JUHY	5	*Junco hyemalis*	northern junco
LAAR	3	*Larus argentatus*	herring gull
LACA	3	*Larus californicus*	California gull
LACI	9	*Lasiurus cinereus*	hoary bat
LACU	15	*lagurus curtatus*	sage vole
LADE	3	*Larus delawarensis*	ringed-billed gull
LAEX	7	*Lanius excubitor*	northern shrike
LALU	7	*Lanius ludovicianus*	loggerhead shrike
LANO	14	*Lasionycteris noctivagans*	silver-haired bat
LAPH	3	*Larus philadelphia*	Bonaparte's gull
LAPI	3	*Larus pipixcan*	Franklin's gull
LEAT	4	*Leucosticte atrata*	black rosy finch
LECA	5	*Lepus californicus*	black-tailed jackrabbit
LETO	5	*Lepus townsendi*	white-tailed jackrabbit
LIFE	3	*Limosa fedoa*	marbled godwit
LISC	3	*Limodromus scolopaceus*	long-billed dowitcher
LOCA	5	*Lophortyx californicus*	California quail
LOCO	14	*Lophodytes cucullatus*	hooded merganser
LOLO	3	*Lobipes lobates*	northern phalarope
LUCA	16	*Lutra canadensis*	river otter
LYRU	4	*Lynx rufus*	bobcat
MAFL	4	*Marmota flaviventris*	yellow-bellied marmot
MATA	5	*Masticophis taeniatus*	striped whipsnake
MEAL	16	*Megaceryle alcyon*	belted kingfisher
MELE	13	*Melanerpes lewis*	Lewis' woodpecker
MELI	6	*Melospiza lincolnii*	Lincoln's sparrow
MEMEL	7	*Melospiza melodia*	song sparrow
MEMEP	15	*Mephitis mephitis*	striped skunk
MEMER	14	*Mergus merganser*	common merganser
MESE	3	*Mergus serrator*	red-breasted merganser
MILO	15	*Microtus longicaudis*	long-tailed vole
MIME	15	*Microdipodops megacephalus*	dark kangaroo mouse
MIMO	15	*Microtus montanus*	montane vole
MIPO	7	*Mimulus polyglottos*	northern mockingbird
MOAT	7	*Molothrus ater*	brown-headed cowbird
MUER	15	*Mustela erminea*	short-tailed weasel
MUFR	15	*Mustela frenata*	long-tailed weasel
MUVI	16	*Mustela vison*	mink
MYCA	4	*Myotis californicus*	California myotis

Letter code	Life form	Scientific name	Common name
MYCI	14	*Myiarchus cinerascens*	ash-throated flycatcher
MYEV	14	*Myotis evotis*	long-eared myotis
MYLE	4	*Myotis leibi*	small-footed myotis
MYLU	4	*Myotis lucifugus*	little brown myotis
MYTH	4	*Myotis thysanodes*	fringed myotis
MYTO	6	*Myadestes townsendi*	Townsend's solitaire
MYVO	14	*Myotis volans*	long-legged myotis
MYYU	14	*Myotis yumanensis*	Yuma myotis
NECI	4	*Neotoma cinerea*	bushy-tailed woodrat
NELE	4	*Neotoma lepida*	desert woodrat
NUAM	3	*Numenius americanus*	long-billed curlew
NUBO	10	*Nuttallornis borealis*	olive-sided flycatcher
NUCO	10	*Nucifraga columbiana*	Clark's nutcracker
NYNY	7	*Nycticorax nycticorax*	black-crowned night heron
ODHE	5	*Odocoileus hemionus*	mule deer
OLCO	3	*Olor columbianus*	whistling swan
ONLE	15	*Onychomys leucogastor*	northern grasshopper mouse
ONZI	16	*Ondatra zibethicus*	muskrat
OPTO	7	*Oporornis tolmiei*	MacGillivray's warbler
ORMO	7	*Oreoscoptes montanus*	sage thrasher
ORPI	5	*Oreortyx pictus*	mountain quail
OTAS	14	*Otus asio*	common screech owl
OTFL	14	*Otus flammeolus*	flammulated owl
OVCA	5	*Ovis canadensis*	bighorn sheep
OXJA	3	*Oxyura jamaicensis*	ruddy duck
PAAMO	7	*Passerina amoena*	lazuli bunting
PAATR	14	*Parus atricapillus*	black-capped chickadee
PACY	8	*Passerina cyanea*	indigo bunting
PADO	14	*Passer domesticus*	house sparrow
PAGA	14	*Parus gambeli*	mountain chickadee

Letter code	Life form	Scientific name	Common name
PAHA	12	*Pandion haliaetus*	osprey
PAIL	7	*Passerella iliaca*	fox sparrow
PASA	5	*Passerculus sandwichensis*	savannah sparrow
PECA	11	*Perisoreus canadensis*	gray jay
PECR	4	*Peromyscus crinitis*	canyon mouse
PEERY	3	*Pelecanus erythrorhynchos*	American white pelican
PELO	15	*Perognathus longimembris*	little pocket mouse
PEMA	15	*Peromyscus maniculatus*	deer mouse
PEPA	15	*Perognathus parvus*	Great Basin pocket mouse
PEPER	5	*Perdix perdix*	grey partridge
PEPY	4	*Petrochelidon pyrrhonota*	cliff swallow
PHAU	3	*Phalacrocorax auritus*	double-crested cormorant
PHCOL	5	*Phasianus colchicus*	ring-necked pheasant
PHDO	5	*Phrynosoma douglassi*	short-horned lizard
PHLU	9	*Pheucticus ludovicianus*	rose-breasted grosbeak
PHME	11	*Pheucticus melanocephalus*	black-headed grosbeak
PHNU	6	*Phalaenoptilus nuttalli*	poorwill
PHPL	5	*Phrynosoma platyrhinos*	desert horned lizard
PIAL	13	*Picoides albolarvatus*	white-headed woodpecker
PICH	7	*Pipilo chlorura*	green-tailed towhee
PIER	7	*Pipilo erythrophthalmus*	rufous-sided towhee
PIHE	4	*Pipistrellus hesperus*	western pipistrelle
PILU	10	*Piranga ludoviciana*	western tanager western tanager
PIME	5	*Pituophis melanoleucus*	gopher snake
PIPI	7	*Pica pica*	black-billed magpie
PIPU	13	*Picoides pubescens*	downy woodpecker
PIVI	13	*Picoides villosus*	hairy woodpecker

Letter code	Life form	Scientific name	Common name
PLCH	7	*Plegadis chihi*	white-faced ibis
PLNI	5	*Plectrophenax nivalis*	snow bunting
PLTO	4	*Plecotus townsendi*	western big-eared bat
POAU	3	*Podiceps auritus*	horned grebe
POCAE	7	*Polioptila caerula*	blue-grey gnatcatcher
POCAR	3	*Porzana carolina*	sora
POGRA	5	*Pooecetes gramineus*	vesper sparrow
POGRI	3	*Podiceps grisegena*	red-necked grebe
PONIGR	3	*Podiceps nigricollis*	eared grebe
POPO	3	*Podilymbus podiceps*	pied-billed grebe
PRLO	14	*Procyon lotor*	raccoon
PSMI	8	*Psaltriparus minimus*	bushtit
RACA	1	*Rana catesbiana*	bullfrog
RALI	3	*Rallus limicola*	Virginia rail
RANO	5	*Rattus norvegicus*	Norway rat
RAPI	2	*Rana pipens*	leopard frog
RAPR	1	*Rana pretiosa*	spotted frog
RARA	5	*Rattus rattus*	black rat
REAM	3	*Recurvirostra americana*	American avocet
RECA	10	*Regulus calendula*	ruby-crowned kinglet
REME	15	*Reithrodontomys megalotis*	western harvest mouse
RESA	10	*Regulus satrapa*	golden-crowned kinglet
RIRI	16	*Riparia riparia*	bank swallow
SAOB	4	*Salpinctes obsoletus*	rock wren
SASA	4	*Sayornis saya*	Say's phoebe
SCGR	5	*Sceloporus graciosus*	sagebrush lizard
SCIN	2	*Schaphiopus intermontanus*	Great Basin spadefoot
SCOC	4	*Sceloporus occidentalis*	western fence lizard
SEAU	7	*Seiurus aurocapillus*	ovenbird
SEPL	7	*Selasphorus platycerus*	broad-tailed hummingbird
SERUF	11	*Selasphorus rufus*	rufous hummingbird
SERUT	9	*Setophaga ruticilla*	American redstart
SICAN	13	*Sitta canadensis*	red-breasted nuthatch
SICAR	13	*Sitta carolinensis*	white-breasted nuthatch
SICU	14	*Sialia currucoides*	mountain bluebird
SIME	14	*Sialia mexicanus*	western bluebird
SOME	15	*Sorex merriami*	Merriam shrew
SOPR	16	*Sorex preblei*	Malheur shrew
SOSE	15	*Sonora semiannulata*	western ground snake
SOSP	3	*Somateria spectabilis*	king eider
SOVA	16	*Sorex vagrans*	wandering shrew
SPARB	11	*Spizella arborea*	American tree sparrow
SPBE	15	*Spermophilus beldingi*	Belding ground squirrel
SPBRE	7	*Spizella breweri*	Brewer's sparrow
SPCO	15	*Spermophilus columbianus*	Columbian ground squirrel
SPLA	15	*Spermophilus lateralis*	mantled ground squirrel
SPPA	7	*Spizella passerina*	chipping sparrow
SPPU	4	*Spilogale putorius*	spotted skunk
SPRI	15	*Spermophilus richardsoni*	Richardson ground squirrel
SPTH	13	*Sphyrapicus thyroideus*	Williamson's sapsucker
SPTO	15	*Spermophilus townsendi*	Townsend ground squirrel
SPVAR	13	*Sphyrapicus varius*	yellow-bellied sapsucker
STCAL	7	*Stellula calliope*	calliope hummingbird
STCAS	3	*Sterna caspia*	Caspian tern
STFO	3	*Sterna forsteri*	Forster's tern
STNEG	5	*Sturnella neglecta*	western meadowlark
STRU	16	*Stelgidopteryx ruficollis*	rough-winged swallow
STTRI	3	*Steganopus tricolor*	Wilson's phalarope
STVU	14	*Sturnus vulgarius*	European starling
SYID	5	*Sylvilagus idahoensis*	pygmy rabbit
SYNU	5	*Sylvilagus nuttalli*	mountain cottontail

Letter code	Life form	Scientific name	Common name
TATA	15	*Taxidea taxus*	badger
TATH	14	*Tachycineta thalassina*	violet-green swallow
THEL	3	*Thamnophis elegans*	wandering garter snake
THSI	3	*Thamnophis sirtalis*	common garter snake
THTA	15	*Thomomys talpoides*	northern pocket gopher
THTO	15	*Thomomys townsendi*	Townsend pocket gopher
TORU	7	*Toxostoma rufum*	brown thrasher
TRAE	14	*Troglodytes aedon*	house wren
TRTR	3	*Troglodytes troglodytes*	winter wren
TUMI	7	*Turdus migratorius*	American robin
TRFL	3	*Tringa flavipes*	lesser yellowlegs
TRME	3	*Tringa melanoleuca*	greater yellowlegs
TRSO	7	*Tringa solitaria*	solitary sandpiper
TYAL	14	*Tyto alba*	barn owl

Letter code	Life form	Scientific name	Common name
TYTY	7	*Tyrannus tyrannus*	eastern kingbird
TYVE	11	*Tyrannus verticalis*	western kingbird
UTST	5	*Uta stansburiana*	side-blotched lizard
VECE	6	*Vermivora celata*	orange-crowned warbler
VIGI	11	*Vireo gilvus*	warbling vireo
VIOL	11	*Vireo olivaceus*	red-eyed vireo
VISO	11	*Vireo solitarius*	solitary vireo
VUMA	15	*Vulpes macrotis*	kit fox
VUVU	15	*Vulpes vulpes*	red fox
WIPU	5	*Wilsonia pusilla*	Wilson's warbler
XAXA	7	*Xanthocephalus xanthocephalus*	yellow-headed blackbird
ZAPR	15	*Zapus princeps*	western jumping mouse
ZEMA	11	*Zenaida macroura*	mourning dove
ZOAT	7	*Zonotrichia atricapilla*	golden-crowned sparrow
ZOLE	7	*Zonotrichia leucophrys*	white-crowned sparrow

Appendix 3. Relative degree of use, by the life form, of plant communities and structural conditions (overstory and understory). Life form 1: reproduces in water, feeds in water. (2 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

		Structural conditions														
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
Plant community	Function	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch	B.G.	Ann	Bunch.	B.G.	Ann.	Bunch
crested wheatgrass (seeded)	R 0															
	F 0															
subalpine bunchgrass	R 0															
	F 0															
permanently wet meadows	R 0															
	F 0															
seasonally wet meadows	R 0															
	F 0															
shadscale saltbush bunchgrass	R 0															
	F 0															
low sagebrush/bunchgrass	R 0															
	F 0															
black greasewood grass	R 0															
	F 0															
tall sagebrush/bunchgrass	R 0															
	F 0															
squaw apple/bunchgrass	R 0															
	F 0															
curlleaf mountainmahogany bunchgrass	R 0															
	F 0															
curlleaf mountainmahogany/ pinegrass	R 0															
	F 0															
juniper/sagebrush bunchgrass	R 0															
	F 0															
curlleaf mountainmahogany/ shrub	R 0															
	F 0															
quaking aspen/grass	R 0															
	F 0															
quaking aspen/mountain big sagebrush/bunchgrass	R 0															
	F 0															
riparian	R 2	2	2			2			2			2			2	
	F 2	2	2			2			2			2			2	

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 2: reproduces in water; feeds on ground, in shrubs, and/or in trees. (6 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function	Structural conditions: Grass-forb B.G.	Grass-forb Ann.	Grass-forb Bunch.	Low shrub B.G.	Low shrub Ann.	Low shrub Bunch.	Tall shrub B.G.	Tall shrub Ann.	Tall shrub Bunch.	Tree B.G.	Tree Ann.	Tree Bunch.	Tree/shrub B.G.	Tree/shrub Ann.	Tree/shrub Bunch.
crested wheatgrass (seeded)	R 1		1	0												
	F 2		2	1												
subalpine bunchgrass	R 0		0	0												
	F 1		1	1												
permanently wet meadows	R 2		2	0												
	F 5		5	2												
seasonally wet meadows	R 0		0	0												
	F 4		4	2												
shadscale saltbush/ bunchgrass	R 0															
	F 0															
low sagebrush/bunchgrass	R 0															
	F 0															
black greasewood/grass	R 0															
	F 0															
tall sagebrush/bunchgrass	R 3				3	0	1	3	0	1						
	F 3				2	3	2	2	3	2						
squaw apple/bunchgrass	R 0					0			0							
	F 1					1			1							
curlleaf mountainmahogany/ bunchgrass	R 0				0	0	0	0	0	0		0	0			
	F 1				1	1	1	1	1	1		1	1			
curlleaf mountainmahogany/ pinegrass	R 0				0	0	0	0	0	0		0	0			
	F 1				1	1	1	1	1	1		1	1			
juniper/sagebrush/ bunchgrass	R 0															
	F 0															
curlleaf mountainmahogany/ shrub	R 0															
	F 0															
quaking aspen/grass	R 0				0	0	0	0	0	0	0	0	0	0	0	0
	F 4				2	4	2	2	4	2	1	4	4	1	3	2
quaking aspen/mountain big sagebrush/bunchgrass	R 0				0	0	0	0	0	0	0	0	0	0	0	0
	F 3				1	3	0	1	3	1	1	3	3	1	3	2
riparian	R 6				6	0	1	6	0	1	5	0	1	1	2	3
	F 6				2	6	3	2	6	3	1	5	5	1	3	3

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 3: reproduces on ground around water or on floating or emergent vegetation; feeds in water, on ground, in shrubs and trees. (44 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

		Structural conditions														
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
Plant community	Function	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B G	Ann	Bunch.
crested wheatgrass (seeded)	R 0															
	F 0															
subalpine bunchgrass	R 1	1	1	1												
	F 1	1	1	1												
permanently wet meadows	R 6	3	6	2												
	F 20	7	8	4												
seasonally wet meadows	R 5	3	5	2												
	F 9	7	8	4												
shadscale saltbush bunchgrass	R 1	1	1	1	1	1	1									
	F 1	1	1	1	1	1	1									
low sagebrush/bunchgrass	R 2	1	1	1	2	2	2									
	F 1	1	1	1	1	1	1									
black greasewood/grass	R 2	2	2	2	2	2	2	2	2	2						
	F 2	2	2	2	2	2	2	2	2	2						
tall sagebrush/bunchgrass	R 3	2	2	2	3	3	3	3	3	3						
	F 2	2	2	2	2	2	2	2	2	2						
squaw apple/bunchgrass	R 1	1	1	1	1	1	1	1	1	1						
	F 1	1	1	1	1	1	1	1	1	1						
curlleaf mountainmahogany bunchgrass	R 1	1	1	1	1	1	1	1	1	1	1	1	1			
	F 1	1	1	1	1	1	1	1	1	1	1	1	1			
curlleaf mountainmahogany/ pinegrass	R 1	1	1	1	1	1	1	1	1	1	1	1	1			
	F 1	1	1	1	1	1	1	1	1	1	1	1	1			
juniper/sagebrush bunchgrass	R 2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	F 2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
curlleaf mountainmahogany/ shrub	R 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	F 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
quaking aspen/grass	R 0															
	F 2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
quaking aspen/mountain big sagebrush/bunchgrass	R 0															
	F 2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
riparian	R 38	3	25	3	4	35	11	4	28	11	3	6	10	4	25	10
	F 39	20	39	8	19	31	10	14	23	10	8	6	10	9	22	11

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 4: reproduces in cliffs, caves, rims and/or talus; feeds on ground or in air. (33 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.
crested wheatgrass (seeded)	R	4	0	2	4												
	F	10	1	10	2												
subalpine bunchgrass	R	3	0	3	3												
	F	6	2	4	4												
permanently wet meadows	R	2	0	2	2												
	F	10	2	9	9												
seasonally wet meadows	R	1	0	1	1												
	F	9	2	8	8												
shadscale saltbush/bunchgrass	R	6	2	5	5	1	4	4									
	F	11	5	10	10	3	8	8									
low sagebrush/bunchgrass	R	14	3	8	12	2	7	10									
	F	16	5	15	14	3	12	11									
black greasewood/grass	R	8	2	6	7	1	6	6	1	8	8						
	F	11	5	10	10	3	8	8	3	11	11						
tall sagebrush/bunchgrass	R	27	7	17	23	3	13	18	4	19	24						
	F	27	8	25	25	6	19	19	5	27	27						
squaw apple/bunchgrass	R	6	2	4	5	2	3	4	2	5	6						
	F	11	5	10	10	4	7	8	4	11	11						
curlleaf mountainmahogany/bunchgrass	R	8	2	4	5	2	4	4	2	6	7	2	6	7			
	F	13	5	11	11	4	8	8	4	13	13	5	12	12			
curlleaf mountainmahogany/pinegrass	R	8	2	4	5	2	3	4	2	6	7	2	6	7			
	F	13	5	11	11	4	8	8	4	13	13	5	12	12			
juniper/sagebrush/bunchgrass	R	18	6	12	14	3	9	10	4	14	15	5	15	16	5	16	16
	F	21	7	19	19	5	14	14	6	21	21	10	20	20	9	20	20
curlleaf mountainmahogany/shrub	R	8	2	4	5	2	3	4	2	6	7	2	6	7	2	6	7
	F	14	5	12	12	4	9	9	4	14	14	4	13	13	4	13	13
quaking aspen/grass	R	6	0	2	5	0	2	4	0	4	6	0	3	5	0	3	5
	F	9	2	7	7	2	6	6	2	9	9	2	8	8	2	8	8
quaking aspen/mountain big sagebrush/bunchgrass	R	6	0	2	5	0	2	4	0	4	6	0	3	5	0	3	5
	F	10	2	8	8	2	7	7	2	10	10	2	9	9	2	9	9
riparian	R	20	2	14	18	0	12	15	1	14	17	1	14	17	1	14	17
	F	28	4	26	25	4	22	21	5	27	27	7	26	26	8	26	26

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 5: reproduces on ground without specific water, cliff, rim or talus association; feeds on ground.(45 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G	Ann.	Bunch.	B.G.	Ann	Bunch	B.G	Ann	Bunch	B.G	Ann.	Bunch
crested wheatgrass (seeded)	R	3	1	1	2												
	F	6	1	3	4												
subalpine bunchgrass	R	1	0	0	1												
	F	5	0	5	5												
permanently wet meadows	R	6	0	4	2												
	F	16	1	16	12												
seasonally wet meadows	R	5	0	4	2												
	F	14	2	13	11												
shadscale saltbush bunchgrass	R	9	2	2	3	3	6	5									
	F	14	4	9	9	4	13	7									
low sagebrush/bunchgrass	R	22	3	8	9	4	13	14									
	F	24	7	16	17	6	20	16									
black greasewood grass	R	13	1	1	2	2	8	8	2	11	11						
	F	18	3	9	9	5	14	11	5	18	16						
tall sagebrush/bunchgrass	R	31	3	9	6	4	17	15	3	22	21						
	F	32	7	19	17	8	24	19	6	30	25						
squaw apple/bunchgrass	R	5	0	1	3	0	3	4	0	3	4						
	F	14	1	10	12	1	12	12	1	13	13						
curlleaf mountainmahogany bunchgrass	R	7	0	0	2	0	3	3	0	4	6	0	2	4			
	F	19	1	11	13	2	14	13	1	18	17	0	16	16			
curlleaf mountainmahogany pinegrass	R	6	0	0	2	0	2	2	0	3	5	0	1	3			
	F	15	1	10	10	1	11	9	0	14	13	0	13	13			
juniper/sagebrush bunchgrass	R	19	1	2	4	2	10	7	2	14	12	2	7	7	2	11	10
	F	29	3	16	16	5	23	20	5	28	25	3	22	21	3	25	23
curlleaf mountainmahogany/shrub	R	11	0	0	2	1	6	3	1	7	7	1	3	4	1	6	5
	F	17	0	9	9	1	13	10	1	16	14	1	13	13	1	16	15
quaking aspen/grass	R	11	0	1	1	0	6	3	0	9	5	0	3	2	0	9	6
	F	13	0	5	5	0	10	7	0	12	10	1	7	8	1	13	11
quaking aspen/mountain big sagebrush/bunchgrass	R	10	0	1	1	0	5	2	0	8	4	0	2	1	0	8	5
	F	14	0	5	5	0	10	8	0	13	10	0	9	8	0	13	11
riparian	R	22	0	6	2	0	15	7	0	17	11	0	5	4	0	16	10
	F	30	1	17	13	2	24	18	1	27	22	1	19	18	1	27	23

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 6: reproduces on ground; feeds in shrubs, trees, or air. (4 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.
crested wheatgrass (seeded)	R	0															
	F	0															
subalpine bunchgrass	R	0															
	F	0															
permanently wet meadows	R	0		0	0												
	F	2		2	2												
seasonally wet meadows	R	0		0	0												
	F	2		2	2												
shadscale saltbush/ bunchgrass	R	0		0	0	0	0	0									
	F	3		2	2	2	3	3									
low sagebrush/bunchgrass	R	2		0	0	0	2	1									
	F	3		2	2	2	3	3									
black greasewood/grass	R	0		0	0	0	0	0	0	0	0						
	F	3		2	2	2	3	3	2	3	3						
tall sagebrush/bunchgrass	R	3		0	0	0	3	2	0	3	2						
	F	3		2	2	2	3	3	2	3	3						
squaw apple/bunchgrass	R	0		0	0	0	0	0	0	0	0						
	F	3		2	2	2	3	3	2	3	3						
curlleaf mountainmahogany/ bunchgrass	R	1		0	0	0	1	1	0	1	1	0	1	1			
	F	2		1	1	1	2	2	1	2	2	1	2	2			
curlleaf mountainmahogany/ pinegrass	R	0		0	0	0	0	0	0	0	0	0	0	0			
	F	2		1	1	1	2	2	1	2	2	1	2	2			
juniper/sagebrush/ bunchgrass	R	2		0	0	0	2	2	0	2	2	0	2	2	0	2	2
	F	2		1	1	1	2	2	1	2	2	1	2	2	1	2	2
curlleaf mountainmahogany/ shrub	R	1		0	0	0	1	1	0	1	1	0	1	1	0	1	1
	F	2		1	1	1	2	2	1	2	2	1	2	2	1	2	2
quaking aspen/grass	R	1		0	0	0	1	0	0	1	0	0	1	0	0	1	0
	F	3		1	1	1	3	2	1	3	2	1	3	2	1	3	2
quaking aspen/mountain big sagebrush/bunchgrass	R	3		0	0	0	3	2	0	3	2	0	3	2	0	3	2
	F	3		1	1	1	3	2	1	3	2	1	3	2	1	3	2
riparian	R	1		0	0	0	1	0	0	1	0	0	1	0	0	1	0
	F	4		1	1	1	4	3	2	4	3	1	3	2	1	3	2

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 7: reproduces in shrubs; feeds on ground, in water or air. (29 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions															
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub			
			B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch	B.G.	Ann	Bunch	B.G.	Ann	Bunch	B.G.	Ann	Bunch	
crested wheatgrass (seeded)	R	0		0	0													
	F	1		1	1													
subalpine bunchgrass	R	0		0	0													
	F	1		1	1													
permanently wet meadows	R	3		3	0													
	F	10		8	1													
seasonally wet meadows	R	3		3	0													
	F	10		8	0													
shadscale saltbush/bunchgrass	R	0		0	0		0	0										
	F	9		4	1		6	4										
low sagebrush bunchgrass	R	4		0	0		0	0										
	F	14		5	2		8	6										
black greasewood/grass	R	1		0	0		0	0		0	1							
	F	12		5	2		9	6		12	9							
tall sagebrush/bunchgrass	R	18		3	0		6	3		18	14							
	F	21		5	2		12	10		21	18							
squaw apple/bunchgrass	R	2		0	0		1	1		2	2							
	F	15		4	1		11	8		15	12							
curlleaf mountainmahogany/bunchgrass	R	4		0	0		1	1		4	4		2	2				
	F	19		6	2		13	10		19	16		14	12				
curlleaf mountainmahogany/pinegrass	R	4		0	0		1	1		4	4		2	2				
	F	19		6	2		13	10		19	16		14	12				
juniper/sagebrush/bunchgrass	R	18		2	0		4	2		17	13		11	7		18	14	
	F	25		8	2		15	11		25	20		19	15		25	21	
curlleaf mountainmahogany shrub	R	14		0	0		2	2		13	11		7	4		13	10	
	F	26		8	2		15	11		26	21		20	16		26	22	
quaking aspen/grass	R	19		3	0		4	1		19	11		14	7		18	11	
	F	24		9	2		14	10		24	17		20	14		24	18	
quaking aspen/mountain big sagebrush/bunchgrass	R	25		3	0		6	3		25	17		15	8		24	17	
	F	28		9	2		15	11		28	21		22	16		28	22	
riparian	R	23		3	0		4	1		21	14		14	7	1	22	15	
	F	25		10	3		14	10		24	17		20	14	0	24	18	

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 8: reproduces in shrubs; feeds in shrubs, trees, or air. (5 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G	Ann	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.
crested wheatgrass (seeded)	R	0				These plant communities do not achieve a habitat form like that characterized by these structural conditions.											
	F	0															
subalpine bunchgrass	R	0															
	F	0															
permanently wet meadows	R	0															
	F	0															
seasonally wet meadows	R	0															
	F	0															
shadscale saltbush/ bunchgrass	R	0					0	0									
	F	1					1	1									
low sagebrush/bunchgrass	R	0					0	0									
	F	1					1	1									
black greasewood/grass	R	0					0	0	0	0	0						
	F	1					1	1	0	1	1						
tall sagebrush/bunchgrass	R	1					0	0	0	1	1						
	F	4					2	2	0	4	4						
squaw apple/bunchgrass	R	0					0	0	0	0	0						
	F	4					2	2	0	4	4						
curlleaf mountainmahogany/ bunchgrass	R	0					0	0	0	0	0	0	0	0			
	F	4					2	2	0	4	4	0	3	3			
curlleaf mountainmahogany/ pinegrass	R	0					0	0	0	0	0	0	0	0			
	F	4					2	2	0	4	4	0	3	3			
juniper/sagebrush/ bunchgrass	R	1					0	0	0	1	1	0	0	0	0	1	1
	F	3					2	2	0	3	3	0	3	3	0	3	3
curlleaf mountainmahogany/ shrub	R	3					0	0	0	3	3	0	1	1	0	3	3
	F	4					2	2	0	4	4	0	3	3	0	4	4
quaking aspen/grass	R	1					0	0	0	1	1	0	1	1	0	1	1
	F	2					2	2	0	2	2	0	2	2	0	2	2
quaking aspen/mountain big sagebrush/bunchgrass	R	4					0	0	0	4	4	0	2	2	0	4	4
	F	4					2	2	0	4	4	0	3	3	0	4	4
riparian	R	5					0	0	0	5	5	0	2	2	0	5	5
	F	5					2	2	0	5	5	0	3	3	0	5	5

Appendix 3. Life form 9: reproduces primarily in deciduous trees; feeds in shrubs, trees, or air. (3 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

			Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
Plant community	Function		B.G.	Ann.	Bunch	B.G	Ann.	Bunch.	B.G	Ann.	Bunch	B.G	Ann	Bunch.	B.G	Ann	Bunch
crested wheatgrass (seeded)	R	0															
	F	0															
subalpine bunchgrass	R	0															
	F	0															
permanently wet meadows	R	0															
	F	0															
seasonally wet meadows	R	0															
	F	0															
shadscale saltbush bunchgrass	R	0															
	F	0															
low sagebrush/bunchgrass	R	0															
	F	0															
black greasewood grass	R	0															
	F	0															
tall sagebrush/bunchgrass	R	0								0	0						
	F	1								1	0						
squaw apple/bunchgrass	R	0								0	0						
	F	1								1	0						
curlleaf mountainmahogany bunchgrass	R	0								0	0		0	0			
	F	1								1	0		1	0			
curlleaf mountainmahogany pinegrass	R	0								0	0		0	0			
	F	1								1	0		1	0			
juniper/sagebrush bunchgrass	R	1								0	0		0	0		1	1
	F	3								3	1		3	2		3	3
curlleaf mountainmahogany shrub	R	1								0	0		0	0		1	1
	F	2								2	0		2	1		2	2
quaking aspen/grass	R	3								2	0		1	0		3	3
	F	3								3	1		3	2		3	3
quaking aspen/mountain big sagebrush/bunchgrass	R	3								2	0		1	0		3	3
	F	3								3	1		3	2		3	3
riparian	R	3								2	0		1	0		3	3
	F	3								3	1		3	2		3	3

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 10: reproduces primarily in conifers; feeds in shrubs, trees, or air. (7 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.
crested wheatgrass (seeded)	R	0															
	F	0															
subalpine bunchgrass	R	0															
	F	0															
permanently wet meadows	R	0															
	F	0															
seasonally wet meadows	R	0															
	F	0															
shadscale saltbush/ bunchgrass	R	0															
	F	0															
low sagebrush/bunchgrass	R	0															
	F	0															
black greasewood/grass	R	0															
	F	0															
tall sagebrush/bunchgrass	R	0					0	0	0	0	0						
	F	2					1	1	0	2	2						
squaw apple/bunchgrass	R	0					0	0	0	0	0						
	F	2					1	1	0	2	2						
curlleaf mountainmahogany/ bunchgrass	R	0					0	0	0	0	0	0	0	0			
	F	2					1	1	0	2	2	0	2	2			
curlleaf mountainmahogany/ pinegrass	R	0					0	0	0	0	0	0	0	0			
	F	2					1	1	0	2	2	0	2	2			
juniper/sagebrush/ bunchgrass	R	3					0	0	0	2	2	0	3	2	0	3	2
	F	5					1	1	0	3	3	1	5	4	1	5	4
curlleaf mountainmahogany/ shrub	R	1					0	0	0	1	1	0	1	1	0	1	1
	F	4					1	1	0	2	3	0	4	3	0	4	3
quaking aspen/grass	R	3					0	0	0	0	0	0	3	0	0	3	0
	F	6					1	1	0	3	3	1	6	4	1	6	4
quaking aspen/mountain big sagebrush/bunchgrass	R	5					0	0	0	1	1	0	4	1	0	5	2
	F	6					1	1	0	3	3	1	6	4	1	6	4
riparian	R	5					0	0	0	1	1	0	4	1	0	5	1
	F	7					1	1	0	3	3	1	6	4	1	6	4

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 11: reproduces in trees; feeds on ground, in shrubs, trees, or air. (13 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree shrub		
			B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch	B.G.	Ann	Bunch	B.G.	Ann	Bunch
crested wheatgrass (seeded)	R	0		0													
	F	1		1													
subalpine bunchgrass	R	0		0													
	F	3		1													
permanently wet meadows	R	0		0													
	F	4		3													
seasonally wet meadows	R	0		0													
	F	4		4													
shadscale saltbush/bunchgrass	R	0		0			0	0									
	F	2		4			2	1									
low sagebrush/bunchgrass	R	1		0			0	0									
	F	2		2			1	1									
black greasewood/grass	R	1		0			0	0		1	1						
	F	2		2			1	1		2	0						
tall sagebrush/bunchgrass	R	3		0			0	0		2	1						
	F	7		4			4	1		6	1						
squaw apple/bunchgrass	R	0		0			0	0		0	0						
	F	6		2			4	2		6	1						
curlleaf mountainmahogany/bunchgrass	R	1		0			0	0		1	1	1	1	1			
	F	8		4			5	2		7	2	0	8	2			
curlleaf mountainmahogany/pinegrass	R	1		0			0	0		1	1	1	1	1			
	F	8		4			5	2		7	2	0	8	2			
juniper/sagebrush/bunchgrass	R	5		0			0	0		1	1	1	5	1	2	5	3
	F	10		4			4	2		8	2	0	10	2	1	10	7
curlleaf mountainmahogany/shrub	R	2		0			0	0		1	1	1	2	1	1	2	2
	F	8		4			5	2		7	2	0	8	2	1	8	5
quaking aspen/grass	R	13		0			0	0		2	1	1	10	3	2	12	9
	F	13		4			5	2		8	2	0	12	3	1	13	8
quaking aspen/mountain big sagebrush/bunchgrass	R	12		0			0	0		2	1	1	10	2	2	12	8
	F	13		4			5	2		8	2	0	12	3	1	13	8
riparian	R	13		0			0	0		2	1	1	10	3	2	12	9
	F	13		4			5	2		8	2	0	12	3	1	13	8

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 12: reproduces on very thick branches; feeds on ground or in water. (6 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.
crested wheatgrass (seeded)	R	0		0	0												
	F	1		1	1												
subalpine bunchgrass	R	0		0	0												
	F	2		2	2												
permanently wet meadows	R	0		0	0												
	F	5		5	3												
seasonally wet meadows	R	0		0	0												
	F	5		5	3												
shadscale saltbush/ bunchgrass	R	0		0	0		0	0									
	F	3		3	3		3	3									
low sagebrush/bunchgrass	R	0		0	0		0	0									
	F	3		3	3		3	3									
black greasewood/grass	R	0		0	0		0	0		0	0						
	F	3		3	3		3	3		3	3						
tall sagebrush/bunchgrass	R	3		0	0		0	0		0	0						
	F	3		3	3		3	3		3	3						
squaw apple/bunchgrass	R	0		0	0		0	0		0	0						
	F	3		3	3		3	3		3	3						
curlleaf mountainmahogany/ bunchgrass	R	0		0	0		0	0		0	0	0	0	0			
	F	3		3	3		3	3		3	3	0	3	3			
curlleaf mountainmahogany/ pinegrass	R	0		0	0		0	0		0	0	0	0	0			
	F	3		3	3		3	3		3	3	0	3	3			
juniper/sagebrush/ bunchgrass	R	5		0	0		0	0		2	0	5	5	5	5	5	5
	F	3		3	3		3	3		3	3	0	3	3	0	3	3
curlleaf mountainmahogany/ shrub	R	3		0	0		0	0		0	0	0	3	3	0	3	3
	F	3		3	3		3	3		3	3	0	3	3	0	3	3
quaking aspen/grass	R	4		0	0		0	0		2	0	4	4	4	4	4	4
	F	3		3	3		3	3		3	3	0	3	3	0	3	3
quaking aspen/mountain big sagebrush/bunchgrass	R	4		0	0		0	0		2	0	4	4	4	4	4	4
	F	3		3	3		3	3		3	3	0	3	3	0	3	3
riparian	R	6		0	0		0	0		2	0	5	5	6	5	5	6
	F	5		5	3		3	3		3	3	0	3	3	0	3	3

Structural conditions

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 13: reproduces – excavates own hole in a tree; feeds on ground, in shrubs, trees, or air. (9 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G	Ann.	Bunch.	B.G	Ann.	Bunch	B.G	Ann.	Bunch	B.G	Ann.	Bunch
crested wheatgrass (seeded)	R	0	0														
	F	0	0														
subalpine bunchgrass	R	0	0														
	F	0	0														
permanently wet meadows	R	0	0														
	F	0	0														
seasonally wet meadows	R	0	0														
	F	0	0														
shadscale saltbush/bunchgrass	R	0	0			0											
	F	1	1			1											
low sagebrush/bunchgrass	R	0	0			0											
	F	1	1			1											
black greasewood/grass	R	0	0			0			0								
	F	1	1			1			1								
tall sagebrush/bunchgrass	R	0	0			0			0								
	F	1	1			1			1								
squaw apple/bunchgrass	R	0	0			0			0								
	F	1	1			1			1								
curlleaf mountainmahogany/bunchgrass	R	0	0			0			0			0	0	0			
	F	1	1			1			1			1	1	1			
curlleaf mountainmahogany/pinegrass	R	0	0			0			0			0	0	0			
	F	1	1			1			1			1	1	1			
juniper/sagebrush/bunchgrass	R	6	0			0			0			3	5	3	5	6	6
	F	6	1			1			3			3	5	3	5	6	6
curlleaf mountainmahogany/shrub	R	0	0			0			0			0	0	0	0	0	0
	F	1	1			1			1			1	1	1	1	1	1
quaking aspen/grass	R	6	0			0			0			2	5	2	4	6	6
	F	9	1			2			5			4	8	4	6	9	9
quaking aspen/mountain big sagebrush/bunchgrass	R	6	0			0			0			2	5	2	4	6	6
	F	9	1			2			5			4	8	4	6	9	9
riparian	R	8	0			0			0			3	7	3	5	8	8
	F	9	1			2			5			4	8	4	6	9	9

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 14: reproduces in a hole made by another species or that has occurred naturally; feeds on ground, in water, or air. (25 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann	Bunch.	B.G.	Ann.	Bunch.	B.G	Ann.	Bunch.
crested wheatgrass (seeded)	R	0		0	0												
	F	0		0	0												
subalpine bunchgrass	R	0		0	0												
	F	0		0	0												
permanently wet meadows	R	0		0	0												
	F	12		10	3												
seasonally wet meadows	R	0		0	0												
	F	12		10	3												
shadscale saltbush/ bunchgrass	R	0		0	0		0	0									
	F	6		2	2		2	6									
low sagebrush/bunchgrass	R	0		0	0		0	0									
	F	11		6	2		4	7									
black greasewood/grass	R	0		0	0		0	0		0	0						
	F	6		2	2		2	6		2	6						
tall sagebrush/bunchgrass	R	0		0	0		0	0		0	0						
	F	15		8	3		7	10		11	10						
squaw apple/bunchgrass	R	0		0	0		0	0		0	0						
	F	7		3	3		3	7		3	7						
curlleaf mountainmahogany/ bunchgrass	R	0		0	0		0	0		0	0	0	0	0			
	F	6		2	2		2	6		2	6	5	5	5			
curlleaf mountainmahogany/ pinegrass	R	0		0	0		0	0		0	0	0	0	0			
	F	10		3	2		4	8		5	8	6	8	7			
juniper/sagebrush/ bunchgrass	R	10		0	0		0	0		0	0	3	9	6	4	9	6
	F	14		6	3		5	8		9	8	6	12	9	8	13	10
curlleaf mountainmahogany/ shrub	R	1		0	0		0	0		0	0	0	1	0	0	1	0
	F	13		5	2		4	8		8	8	6	11	9	7	12	10
quaking aspen/grass	R	15		0	0		0	0		0	0	5	11	7	6	11	8
	F	15		8	3		8	5		13	5	3	11	7	4	11	8
quaking aspen/mountain big sagebrush/bunchgrass	R	15		0	0		0	0		0	0	5	11	7	6	11	8
	F	15		8	3		8	5		13	5	3	11	7	4	11	8
riparian	R	24		0	0		0	0		0	0	8	19	14	10	21	16
	F	24		11	3		10	11		16	11	6	17	12	8	19	14

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 15: reproduces – underground burrow; feeds on or under ground. (32 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

			Structural conditions													
			Grass-forb			Low shrub			Tall shrub			Tree			Tree shrub	
Plant community	Function		B.G.	Ann.	Bunch	B.G	Ann.	Bunch.	B.G	Ann.	Bunch	B.G	Ann.	Bunch.	B.G	Ann.	Bunch
crested wheatgrass (seeded)	R	8	0	3	5												
	F	8	0	6	6												
subalpine bunchgrass	R	9	0	2	6												
	F	9	0	5	7												
permanently wet meadows	R	10	0	4	7												
	F	11	0	7	9												
seasonally wet meadows	R	7	0	2	4												
	F	8	0	5	6												
shadscale saltbush bunchgrass	R	13	0	4	4	0	6	9									
	F	13	1	5	5	1	7	9									
low sagebrush/bunchgrass	R	13	0	5	7	0	5	10									
	F	13	1	7	8	1	8	10									
black greasewood grass	R	12	0	3	3	0	3	6	0	6	10						
	F	13	1	5	5	1	5	7	1	8	10						
tall sagebrush/bunchgrass	R	22	0	5	10	0	6	12	0	12	15						
	F	22	1	8	11	1	8	12	1	14	16						
squaw apple/bunchgrass	R	4	0	1	1	0	1	2	0	3	4						
	F	5	0	3	3	0	2	3	0	3	4						
curlleaf mountainmahogany bunchgrass	R	6	0	1	1	0	1	3	0	3	6		4	6			
	F	6	0	3	2	0	2	3	0	4	6		5	6			
curlleaf mountainmahogany/ pinegrass	R	6	0	1	1	0	1	3	0	3	6		4	6			
	F	6	0	3	2	0	2	3	0	4	6		5	6			
juniper/sagebrush/ bunchgrass	R	12	0	1	4	0	1	6	0	9	12		9	13		9	13
	F	12	0	4	5	0	3	6	0	9	12		10	13		10	13
curlleaf mountainmahogany shrub	R	6	0	1	1	0	1	3	0	3	6		4	6		4	6
	F	6	0	3	2	0	2	3	0	4	6		5	6		5	6
quaking aspen/grass	R	2	0	1	1	0	1	1	0	2	2		2	2		2	2
	F	2	0	1	1	0	1	1	0	2	2		2	2		2	2
quaking aspen/mountain big sagebrush/bunchgrass	R	2	0	1	1	0	1	1	0	2	2		2	2		2	2
	F	2	0	1	1	0	1	1	0	2	2		2	2		2	2
riparian	R	15	0	3	7	0	3	7	0	8	9		7	11		10	14
	F	16	0	6	9	0	5	8	0	8	9		9	12		10	14

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 3. Life form 16: reproduces – underground burrow; feeds in water, on ground, or in air. (9 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.
crested wheatgrass (seeded)	R	0		0	0												
	F	0		0	0												
subalpine bunchgrass	R	2		0	2												
	F	2		0	2												
permanently wet meadows	R	2		0	2												
	F	4		2	2												
seasonally wet meadows	R	0		0	0												
	F	2		2	0												
shadscale saltbush/bunchgrass	R	0		0	0		0	0									
	F	0		0	0		0	0									
low sagebrush/bunchgrass	R	0		0	0		0	0									
	F	0		0	0		0	0									
black greasewood/grass	R	0		0	0		0	0		0	0						
	F	0		0	0		0	0		0	0						
tall sagebrush/bunchgrass	R	1		0	1		0	1		0	1						
	F	3		2	1		2	3		2	3						
squaw apple/bunchgrass	R	0		0	0		0	0		0	0						
	F	0		0	0		0	0		0	0						
curlleaf mountainmahogany/bunchgrass	R	0		0	0		0	0		0	0		0	0			
	F	0		0	0		0	0		0	0		0	0			
curlleaf mountainmahogany/pinegrass	R	0		0	0		0	0		0	0		0	0			
	F	0		0	0		0	0		0	0		0	0			
juniper/sagebrush/bunchgrass	R	0		0	0		0	0		0	0		0	0		0	0
	F	0		0	0		0	0		0	0		0	0		0	0
curlleaf mountainmahogany/shrub	R	0		0	0		0	0		0	0		0	0		0	0
	F	0		0	0		0	0		0	0		0	0		0	0
quaking aspen/grass	R	0		0	0		0	0		0	0		0	0		0	0
	F	2		2	0		2	2		2	2		2	2		2	2
quaking aspen/mountain big sagebrush/bunchgrass	R	0		0	0		0	0		0	0		0	0		0	0
	F	2		2	0		2	2		2	2		2	2		2	2
riparian	R	9		0	2		2	4		5	7		3	5		6	8
	F	9		4	2		2	4		5	7		6	5		6	8

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Relative degree of use, by the life form, of plant communities and structural conditions (overstory without the refinements of the understory in appendix 3). Life form 1: reproduces in water; feeds in water. (2 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.
crested wheatgrass (seeded)	R	0															
	F	0															
subalpine bunchgrass	R	0															
	F	0															
permanently wet meadows	R	0															
	F	0															
seasonally wet meadows	R	0															
	F	0															
shadscale saltbush/bunchgrass	R	0															
	F	0															
low sagebrush/bunchgrass	R	0															
	F	0															
black greasewood grass	R	0															
	F	0															
tall sagebrush/bunchgrass	R	0															
	F	0															
squaw apple/bunchgrass	R	0															
	F	0															
curlleaf mountainmahogany bunchgrass	R	0															
	F	0															
curlleaf mountainmahogany pinegrass	R	0															
	F	0															
juniper/sagebrush bunchgrass	R	0															
	F	0															
curlleaf mountainmahogany/shrub	R	0															
	F	0															
quaking aspen/grass	R	0															
	F	0															
quaking aspen/mountain big sagebrush/bunchgrass	R	0															
	F	0															
riparian	R	2	2			2			2			2			2		
	F	2	2			2			2			2			2		

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 2: reproduces in water; feeds on ground, in shrubs, and/or in trees. (6 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.
crested wheatgrass (seeded)	R	0	1														
	F	0	2														
subalpine bunchgrass	R	0	0														
	F	1	1														
permanently wet meadows	R	2	2														
	F	5	5														
seasonally wet meadows	R	0	0														
	F	4	4														
shadscale saltbush/ bunchgrass	R	0															
	F	0															
low sagebrush/bunchgrass	R	0															
	F	0															
black greasewood/grass	R	0															
	F	0															
tall sagebrush/bunchgrass	R	3				3			3								
	F	3				3			3								
squaw apple/bunchgrass	R	0				0			0								
	F	1				1			1								
curlleaf mountainmahogany/ bunchgrass	R	0				0			0			0					
	F	1				1			1			1					
curlleaf mountainmahogany/ pinegrass	R	0				0			0			0					
	F	1				1			1			1					
juniper/sagebrush/ bunchgrass	R	0															
	F	0															
curlleaf mountainmahogany/ shrub	R	0															
	F	0															
quaking aspen/grass	R	0				0			0			0			0		
	F	4				4			4			4			3		
quaking aspen/mountain big sagebrush/bunchgrass	R	0				0			0			0			0		
	F	3				3			3			3			3		
riparian	R	6				6			6			5			3		
	F	6				6			6			5			3		

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 3: reproduces on ground around water, or on floating or emergent vegetation; feeds in water, on ground, in shrubs and trees. (44 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions				
			Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
			B.G. Ann. Bunch.	B.G Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch	B.G Ann. Bunch
crested wheatgrass (seeded)	R	0					
	F	0					
subalpine bunchgrass	R	1	1				
	F	1	1				
permanently wet meadows	R	6	6				
	F	20	20				
seasonally wet meadows	R	5	5				
	F	9	9				
shadscale saltbush/ bunchgrass	R	1	1	1			
	F	1	1	1			
low sagebrush/bunchgrass	R	2	1	1			
	F	1	1	1			
black greasewood/grass	R	2	2	2	2		
	F	2	2	2	2		
tall sagebrush/bunchgrass	R	2	2	2	2		
	F	2	2	2	2		
squaw apple/bunchgrass	R	1	1	1	1		
	F	1	1	1	1		
curlleaf mountainmahogany/ bunchgrass	R	1	1	1	1	1	
	F	1	1	1	1	1	
curlleaf mountainmahogany/ pinegrass	R	1	1	1	1	1	
	F	1	1	1	1	1	
juniper/sagebrush/ bunchgrass	R	2	2	2	2	2	2
	F	2	2	2	2	2	2
curlleaf mountainmahogany/ shrub	R	1	1	1	1	1	1
	F	1	1	1	1	1	1
quaking aspen/grass	R	0					
	F	2	2	2	2	2	2
quaking aspen/mountain big sagebrush/bunchgrass	R	0					
	F	2	2	2	2	2	2
riparian	R	38	25	35	28	10	25
	F	39	39	31	23	10	22

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 4: reproduces in cliffs, caves, rims and/or talus; feeds on ground or in air. (33 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions: Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
			B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.
crested wheatgrass (seeded)	R	4	4				
	F	10	10				
subalpine bunchgrass	R	3	33				
	F	6	4				
permanently wet meadows	R	2	2				
	F	10	9				
seasonally wet meadows	R	1	1				
	F	9	8				
shadscale saltbush/ bunchgrass	R	6	5	4			
	F	11	10	8			
low sagebrush/bunchgrass	R	14	12	10			
	F	16	15	12			
black greasewood/grass	R	8	7	6	8		
	F	11	10	8	11		
tall sagebrush/bunchgrass	R	27	23	18	24		
	F	27	25	19	27		
squaw apple/bunchgrass	R	6	5	4	6		
	F	11	10	8	11		
curlleaf mountainmahogany/ bunchgrass	R	8	5	4	7	7	
	F	13	11	8	13	12	
curlleaf mountainmahogany/ pinegrass	R	8	5	4	7	7	
	F	13	11	8	13	12	
juniper/sagebrush/ bunchgrass	R	18	14	10	15	16	16
	F	21	19	14	21	20	20
curlleaf mountainmahogany/ shrub	R	8	5	4	7	7	7
	F	14	12	9	14	13	13
quaking aspen/grass	R	6	5	4	6	5	5
	F	9	7	6	9	8	8
quaking aspen/mountain big sagebrush/bunchgrass	R	6	5	4	6	5	5
	F	10	8	7	10	9	9
riparian	R	20	18	15	17	17	17
	F	28	26	22	27	26	26

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 5: reproduces on ground without specific water, cliff, rim or talus association; feeds on ground. (45 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions				
			Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
			B.G. Ann. Bunch.	B.G Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G Ann. Bunch
crested wheatgrass (seeded)	R	3	2				
	F	6	4				
subalpine bunchgrass	R	1	1				
	F	5	5				
permanently wet meadows	R	6	4				
	F	16	16				
seasonally wet meadows	R	5	4				
	F	14	13				
shadscale saltbush bunchgrass	R	9	3	6			
	F	14	9	13			
low sagebrush/bunchgrass	R	22	9	14			
	F	24	17	20			
black greasewood/grass	R	13	2	8	11		
	F	18	9	14	18		
tall sagebrush/bunchgrass	R	31	9	17	22		
	F	32	19	24	30		
squaw apple/bunchgrass	R	5	3	4	4		
	F	14	12	12	13		
curlleaf mountainmahogany/ bunchgrass	R	7	2	3	6	4	
	F	19	13	14	18	16	
curlleaf mountainmahogany/ pinegrass	R	6	2	2	5	3	
	F	15	10	11	14	13	
juniper/sagebrush/ bunchgrass	R	19	4	10	14	7	11
	F	29	16	23	28	22	25
curlleaf mountainmahogany shrub	R	11	2	6	7	4	6
	F	17	9	13	16	13	16
quaking aspen/grass	R	11	1	6	9	3	9
	F	13	5	10	12	8	13
quaking aspen/mountain big sagebrush/bunchgrass	R	10	1	5	8	2	8
	F	14	5	10	13	9	13
riparian	R	22	6	15	17	5	16
	F	30	17	24	27	19	27

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 6: reproduces on ground; feeds in shrubs, trees, or air. (4 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions				
			Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
			B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.
crested wheatgrass (seeded)	R	0					
	F	0					
subalpine bunchgrass	R	0					
	F	0					
permanently wet meadows	R	0	0				
	F	2	2				
seasonally wet meadows	R	0	0				
	F	2	2				
shadscale saltbush/ bunchgrass	R	0	0	0			
	F	3	2	3			
low sagebrush/bunchgrass	R	2	0	2			
	F	3	2	3			
black greasewood/grass	R	0	0	0	0		
	F	3	2	3	3		
tall sagebrush/bunchgrass	R	3	0	3	3		
	F	3	2	3	3		
squaw apple/bunchgrass	R	0	0	0	0		
	F	3	2	3	3		
curlleaf mountainmahogany/ bunchgrass	R	1	0	1	1	1	
	F	2	1	2	2	2	
curlleaf mountainmahogany/ pinegrass	R	0	0	0	0	0	
	F	2	1	2	2	2	
juniper/sagebrush/ bunchgrass	R	2	0	2	2	2	2
	F	2	1	2	2	2	2
curlleaf mountainmahogany/ shrub	R	1	0	1	1	1	1
	F	2	1	2	2	2	2
quaking aspen/grass	R	1	0	1	1	1	1
	F	3	1	3	3	3	3
quaking aspen/mountain big sagebrush/bunchgrass	R	3	0	3	3	3	3
	F	3	1	3	3	3	3
riparian	R	1	0	1	1	1	1
	F	4	1	4	4	3	3

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 7: reproduces in shrubs; feeds on ground, in water or air. (29 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
			B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B G Ann Bunch
crested wheatgrass (seeded)	R	0	0				
	F	1	1				
subalpine bunchgrass	R	0	0				
	F	1	1				
permanently wet meadows	R	3	3				
	F	10	8				
seasonally wet meadows	R	3	3				
	F	10	8				
shadscale saltbush bunchgrass	R	0	0	0			
	F	9	4	6			
low sagebrush/bunchgrass	R	4	0	0			
	F	14	5	8			
black greasewood/grass	R	1	0	0	1		
	F	12	5	9	12		
tall sagebrush/bunchgrass	R	18	3	6	18		
	F	21	5	12	21		
squaw apple/bunchgrass	R	2	0	1	2		
	F	15	4	11	15		
curlleaf mountainmahogany/ bunchgrass	R	4	0	1	4	2	
	F	19	6	13	19	14	
curlleaf mountainmahogany pinegrass	R	4	0	1	4	2	
	F	19	6	13	19	14	
juniper/sagebrush/ bunchgrass	R	18	2	4	17	11	18
	F	25	8	15	25	19	25
curlleaf mountainmahogany/ shrub	R	14	0	2	13	7	13
	F	26	8	15	26	20	26
quaking aspen/grass	R	19	3	4	19	14	18
	F	24	9	14	24	20	24
quaking aspen/mountain big sagebrush/bunchgrass	R	25	3	6	25	15	24
	F	28	9	15	28	22	28
riparian	R	23	3	4	21	14	22
	F	25	10	14	24	20	24

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 8: reproduces in shrubs; feeds in shrubs, trees, or air. (5 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions: Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
			B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.
crested wheatgrass (seeded)	R	0					
	F	0					
subalpine bunchgrass	R	0					
	F	0					
permanently wet meadows	R	0					
	F	0					
seasonally wet meadows	R	0					
	F	0					
shadscale saltbush/ bunchgrass	R	0		0			
	F	1		1			
low sagebrush/bunchgrass	R	0		0			
	F	1		1			
black greasewood/grass	R	0		0	0		
	F	1		1	1		
tall sagebrush/bunchgrass	R	1		0	1		
	F	4		2	4		
squaw apple/bunchgrass	R	0		0	0		
	F	4		2	4		
curlleaf mountainmahogany/ bunchgrass	R	0		0	0	0	
	F	4		2	4	3	
curlleaf mountainmahogany/ pinegrass	R	0		0	0	0	
	F	4		2	4	3	
juniper/sagebrush/ bunchgrass	R	1		0	1	0	1
	F	3		2	3	3	3
curlleaf mountainmahogany/ shrub	R	3		0	3	1	3
	F	4		2	4	3	4
quaking aspen/grass	R	1		0	1	1	1
	F	2		2	2	2	2
quaking aspen/mountain big sagebrush/bunchgrass	R	4		0	4	2	4
	F	4		2	4	3	4
riparian	R	5		0	5	2	5
	F	5		2	5	3	5

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 9: reproduces primarily in deciduous trees; feeds in shrubs, trees, or air. (3 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G.	Ann.	Bunch.	B.G	Ann.	Bunch
crested wheatgrass (seeded)	R	0															
	F	0															
subalpine bunchgrass	R	0															
	F	0															
permanently wet meadows	R	0															
	F	0															
seasonally wet meadows	R	0															
	F	0															
shadscale saltbush bunchgrass	R	0															
	F	0															
low sagebrush/bunchgrass	R	0															
	F	0															
black greasewood/grass	R	0															
	F	0															
tall sagebrush/bunchgrass	R	0								0							
	F	1								1							
squaw apple/bunchgrass	R	0								0							
	F	1								1							
curlleaf mountainmahogany/ bunchgrass	R	0								0			0				
	F	1								1			1				
curlleaf mountainmahogany/ pinegrass	R	0								0			0				
	F	1								1			1				
juniper/sagebrush bunchgrass	R	1								0			0			1	
	F	3								3			3			3	
curlleaf mountainmahogany/ shrub	R	1								0			0			1	
	F	2								2			2			2	
quaking aspen/grass	R	3								2			1			3	
	F	3								3			3			3	
quaking aspen/mountain big sagebrush/bunchgrass	R	3								2			1			3	
	F	3								3			3			3	
riparian	R	3								2			1			3	
	F	3								3			3			3	

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 10: reproduces primarily in conifers; feeds in shrubs, trees, or air. (7 species)

<table>
<tr><th rowspan="3">R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass
Plant community</th><th rowspan="3" colspan="2">Function</th><th colspan="15">Structural conditions</th></tr>
<tr><th colspan="3">Grass-forb</th><th colspan="3">Low shrub</th><th colspan="3">Tall shrub</th><th colspan="3">Tree</th><th colspan="3">Tree/shrub</th></tr>
<tr><th>B.G.</th><th>Ann.</th><th>Bunch.</th><th>B.G</th><th>Ann.</th><th>Bunch.</th><th>B.G.</th><th>Ann.</th><th>Bunch.</th><th>B.G.</th><th>Ann.</th><th>Bunch.</th><th>B.G.</th><th>Ann.</th><th>Bunch.</th></tr>
<tr><td rowspan="2">crested wheatgrass (seeded)</td><td>R</td><td>0</td><td colspan="3"></td><td colspan="12" rowspan="8">These plant communities do not achieve a habitat form like that characterized by these structural conditions.</td></tr>
<tr><td>F</td><td>0</td><td colspan="3"></td></tr>
<tr><td rowspan="2">subalpine bunchgrass</td><td>R</td><td>0</td><td colspan="3"></td></tr>
<tr><td>F</td><td>0</td><td colspan="3"></td></tr>
<tr><td rowspan="2">permanently wet meadows</td><td>R</td><td>0</td><td colspan="3"></td></tr>
<tr><td>F</td><td>0</td><td colspan="3"></td></tr>
<tr><td rowspan="2">seasonally wet meadows</td><td>R</td><td>0</td><td colspan="3"></td></tr>
<tr><td>F</td><td>0</td><td colspan="3"></td></tr>
<tr><td rowspan="2">shadscale saltbush/ bunchgrass</td><td>R</td><td>0</td><td colspan="3"></td><td colspan="3"></td><td colspan="9"></td></tr>
<tr><td>F</td><td>0</td><td colspan="3"></td><td colspan="3"></td><td colspan="9"></td></tr>
<tr><td rowspan="2">low sagebrush/bunchgrass</td><td>R</td><td>0</td><td colspan="3"></td><td colspan="3"></td><td colspan="9"></td></tr>
<tr><td>F</td><td>0</td><td colspan="3"></td><td colspan="3"></td><td colspan="9"></td></tr>
<tr><td rowspan="2">black greasewood/grass</td><td>R</td><td>0</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="6"></td></tr>
<tr><td>F</td><td>0</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="6"></td></tr>
<tr><td rowspan="2">tall sagebrush/bunchgrass</td><td>R</td><td>0</td><td colspan="3"></td><td colspan="3">0</td><td colspan="3">0</td><td colspan="6"></td></tr>
<tr><td>F</td><td>2</td><td colspan="3"></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="6"></td></tr>
<tr><td rowspan="2">squaw apple/bunchgrass</td><td>R</td><td>0</td><td colspan="3"></td><td colspan="3">0</td><td colspan="3">0</td><td colspan="6"></td></tr>
<tr><td>F</td><td>2</td><td colspan="3"></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="6"></td></tr>
<tr><td rowspan="2">curlleaf mountainmahogany/ bunchgrass</td><td>R</td><td>0</td><td colspan="3"></td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3"></td></tr>
<tr><td>F</td><td>2</td><td colspan="3"></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">2</td><td colspan="3"></td></tr>
<tr><td rowspan="2">curlleaf mountainmahogany/ pinegrass</td><td>R</td><td>0</td><td colspan="3"></td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3"></td></tr>
<tr><td>F</td><td>2</td><td colspan="3"></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">2</td><td colspan="3"></td></tr>
<tr><td rowspan="2">juniper/sagebrush/ bunchgrass</td><td>R</td><td>3</td><td colspan="3"></td><td colspan="3">0</td><td colspan="3">2</td><td colspan="3">3</td><td colspan="3">3</td></tr>
<tr><td>F</td><td>5</td><td colspan="3"></td><td colspan="3">1</td><td colspan="3">3</td><td colspan="3">5</td><td colspan="3">5</td></tr>
<tr><td rowspan="2">curlleaf mountainmahogany/ shrub</td><td>R</td><td>1</td><td colspan="3"></td><td colspan="3">0</td><td colspan="3">1</td><td colspan="3">1</td><td colspan="3">1</td></tr>
<tr><td>F</td><td>4</td><td colspan="3"></td><td colspan="3">1</td><td colspan="3">3</td><td colspan="3">4</td><td colspan="3">4</td></tr>
<tr><td rowspan="2">quaking aspen/grass</td><td>R</td><td>3</td><td colspan="3"></td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3">3</td><td colspan="3">3</td></tr>
<tr><td>F</td><td>6</td><td colspan="3"></td><td colspan="3">1</td><td colspan="3">3</td><td colspan="3">6</td><td colspan="3">6</td></tr>
<tr><td rowspan="2">quaking aspen/mountain big sagebrush/bunchgrass</td><td>R</td><td>5</td><td colspan="3"></td><td colspan="3">0</td><td colspan="3">1</td><td colspan="3">4</td><td colspan="3">5</td></tr>
<tr><td>F</td><td>6</td><td colspan="3"></td><td colspan="3">1</td><td colspan="3">3</td><td colspan="3">6</td><td colspan="3">6</td></tr>
<tr><td rowspan="2">riparian</td><td>R</td><td>5</td><td colspan="3"></td><td colspan="3">0</td><td colspan="3">1</td><td colspan="3">4</td><td colspan="3">5</td></tr>
<tr><td>F</td><td>7</td><td colspan="3"></td><td colspan="3">1</td><td colspan="3">3</td><td colspan="3">6</td><td colspan="3">6</td></tr>
</table>

Appendix 4. Life form 11: reproduces in trees; feeds on ground, in shrubs, trees, or air. (13 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions: Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
			B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.
crested wheatgrass (seeded)	R	0	0				
	F	1	1				
subalpine bunchgrass	R	0	0				
	F	3	1				
permanently wet meadows	R	0	0				
	F	4	3				
seasonally wet meadows	R	0	0				
	F	4	4				
shadscale saltbush/bunchgrass	R	0	0	0			
	F	2	4	2			
low sagebrush/bunchgrass	R	1	0	0			
	F	2	2	1			
black greasewood/grass	R	1	0	0	1		
	F	2	2	1	2		
tall sagebrush/bunchgrass	R	3	0	0	2		
	F	7	4	4	6		
squaw apple/bunchgrass	R	0	0	0	0		
	F	6	2	4	6		
curlleaf mountainmahogany/bunchgrass	R	1	0	0	1	1	
	F	8	4	5	7	8	
curlleaf mountainmahogany/pinegrass	R	1	0	0	1	1	
	F	8	4	5	7	8	
juniper/sagebrush bunchgrass	R	5	0	0	1	5	5
	F	10	4	4	8	10	10
curlleaf mountainmahogany/shrub	R	2	0	0	1	2	2
	F	8	4	5	7	8	8
quaking aspen/grass	R	13	0	0	2	11	13
	F	13	4	5	8	12	13
quaking aspen/mountain big sagebrush/bunchgrass	R	12	0	0	2	11	13
	F	13	4	5	8	12	13
riparian	R	13	0	0	2	11	13
	F	13	4	5	8	12	13

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 12: reproduces on very thick branches; feeds on ground or in water. (6 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
			B.G. Ann. Bunch.	B.G Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.
crested wheatgrass (seeded)	R	0	0				
	F	1	1				
subalpine bunchgrass	R	0	0				
	F	2	2				
permanently wet meadows	R	0	0				
	F	5	5				
seasonally wet meadows	R	0	0				
	F	5	5				
shadscale saltbush/ bunchgrass	R	0	0	0			
	F	3	3	3			
low sagebrush/bunchgrass	R	0	0	0			
	F	3	3	3			
black greasewood/grass	R	0	0	0	0		
	F	3	3	3	3		
tall sagebrush/bunchgrass	R	3	0	0	0		
	F	3	3	3	3		
squaw apple/bunchgrass	R	0	0	0	0		
	F	3	3	3	3		
curlleaf mountainmahogany/ bunchgrass	R	0	0	0	0	0	
	F	3	3	3	3	3	
curlleaf mountainmahogany/ pinegrass	R	0	0	0	0	0	
	F	3	3	3	3	3	
juniper/sagebrush/ bunchgrass	R	5	0	0	2	5	5
	F	3	3	3	3	3	3
curlleaf mountainmahogany/ shrub	R	3	0	0	0	3	3
	F	3	3	3	3	3	3
quaking aspen/grass	R	4	0	0	2	4	4
	F	3	3	3	3	3	3
quaking aspen/mountain big sagebrush/bunchgrass	R	4	0	0	2	4	4
	F	3	3	3	3	3	3
riparian	R	6	0	0	2	6	6
	F	5	5	3	3	3	3

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 13: reproduces – excavates own hole in a tree; feeds on ground, in shrubs, trees, or air. (9 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions														
			Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub		
			B.G.	Ann.	Bunch.	B.G	Ann.	Bunch.	B.G.	Ann.	Bunch	B.G	Ann.	Bunch.	B.G	Ann	Bunch
crested wheatgrass (seeded)	R	0	0														
	F	0	0														
subalpine bunchgrass	R	0	0														
	F	0	0														
permanently wet meadows	R	0	0														
	F	0	0														
seasonally wet meadows	R	0	0														
	F	0	0														
shadscale saltbush/ bunchgrass	R	0	0			0											
	F	1	1			1											
low sagebrush/bunchgrass	R	0	0			0											
	F	1	1			1											
black greasewood/grass	R	0	0			0			0								
	F	1	1			1			1								
tall sagebrush/bunchgrass	R	0	0			0			0								
	F	1	1			1			1								
squaw apple/bunchgrass	R	0	0			0			0								
	F	1	1			1			1								
curlleaf mountainmahogany/ bunchgrass	R	0	0			0			0			0					
	F	1	1			1			1			1					
curlleaf mountainmahogany/ pinegrass	R	0	0			0			0			0					
	F	1	1			1			1			1					
juniper/sagebrush/ bunchgrass	R	6	0			0			0			5			6		
	F	6	1			1			3			5			6		
curlleaf mountainmahogany shrub	R	0	0			0			0			0			0		
	F	1	1			1			1			1			1		
quaking aspen/grass	R	6	0			0			0			5			6		
	F	9	1			2			5			8			9		
quaking aspen/mountain big sagebrush/bunchgrass	R	6	0			0			0			5			6		
	F	9	1			2			5			8			9		
riparian	R	8	0			0			0			7			8		
	F	9	1			2			5			8			9		

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 14: reproduces in a hole made by another species or that has occurred naturally; feeds on ground, in water, or air. (25 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
			Structural conditions				
			B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.
crested wheatgrass (seeded)	R	0	0				
	F	0	0				
subalpine bunchgrass	R	0	0				
	F	0	0				
permanently wet meadows	R	0	0				
	F	12	10				
seasonally wet meadows	R	0	0				
	F	12	10				
shadscale saltbush/ bunchgrass	R	0	0	0			
	F	6	2	6			
low sagebrush/bunchgrass	R	0	0	0			
	F	11	6	7			
black greasewood/grass	R	0	0	0	0		
	F	6	2	6	6		
tall sagebrush/bunchgrass	R	0	0	0	0		
	F	15	8	10	11		
squaw apple/bunchgrass	R	0	0	0	0		
	F	7	3	7	7		
curlleaf mountainmahogany/ bunchgrass	R	0	0	0	0	0	
	F	6	2	6	6	5	
curlleaf mountainmahogany/ pinegrass	R	0	0	0	0	0	
	F	10	3	8	8	8	
juniper/sagebrush/ bunchgrass	R	10	0	0	0	9	9
	F	14	6	8	9	12	13
curlleaf mountainmahogany/ shrub	R	1	0	0	0	1	1
	F	13	5	8	8	11	12
quaking aspen/grass	R	15	0	0	0	12	12
	F	15	8	8	13	12	12
quaking aspen/mountain big sagebrush/bunchgrass	R	15	0	0	0	12	12
	F	15	8	8	13	12	12
riparian	R	24	0	0	0	19	21
	F	24	11	11	16	17	19

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 15: reproduces – underground burrow; feeds on or under ground. (32 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch – native bunchgrass

Plant community	Function		Structural conditions				
			Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
			B.G Ann. Bunch.	B.G Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B G Ann Bunch
crested wheatgrass (seeded)	R	8	5				
	F	8	6				
subalpine bunchgrass	R	9	6				
	F	9	7				
permanently wet meadows	R	10	7				
	F	11	9				
seasonally wet meadows	R	7	4				
	F	8	6				
shadscale saltbush/ bunchgrass	R	13	4	9			
	F	13	5	9			
low sagebrush/bunchgrass	R	13	7	10			
	F	13	8	10			
black greasewood/grass	R	12	3	6	10		
	F	13	5	7	10		
tall sagebrush/bunchgrass	R	22	10	12	15		
	F	22	11	12	16		
squaw apple/bunchgrass	R	4	1	2	4		
	F	5	3	3	4		
curlleaf mountainmahogany/ bunchgrass	R	6	1	3	6	6	
	F	6	3	3	6	6	
curlleaf mountainmahogany/ pinegrass	R	6	1	3	6	6	
	F	6	3	3	6	6	
juniper/sagebrush/ bunchgrass	R	12	4	6	12	13	13
	F	12	5	6	12	13	13
curlleaf mountainmahogany/ shrub	R	6	1	3	6	6	6
	F	6	3	3	6	6	6
quaking aspen/grass	R	2	1	1	2	2	2
	F	2	1	1	2	2	2
quaking aspen/mountain big sagebrush/bunchgrass	R	2	1	1	2	2	2
	F	2	1	1	2	2	2
riparian	R	15	7	7	9	11	14
	F	16	9	8	9	12	14

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 4. Life form 16: reproduces – underground burrow; feeds in water, on ground, or in air. (9 species)

R – reproduction
F – feeding
B.G. – bare ground
Ann. – annuals
Bunch. – native bunchgrass

Plant community	Function		Structural conditions				
			Grass-forb	Low shrub	Tall shrub	Tree	Tree/shrub
			B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.	B.G. Ann. Bunch.
crested wheatgrass (seeded)	R	0	0				
	F	0	0				
subalpine bunchgrass	R	2	2				
	F	2	2				
permanently wet meadows	R	2	2				
	F	4	2				
seasonally wet meadows	R	0	0				
	F	2	2				
shadscale saltbush/ bunchgrass	R	0	0	0			
	F	0	0	0			
low sagebrush/bunchgrass	R	0	0	0			
	F	0	0	0			
black greasewood/grass	R	0	0	0	0		
	F	0	0	0	0		
tall sagebrush/bunchgrass	R	1	1	1	1		
	F	3	2	3	3		
squaw apple/bunchgrass	R	0	0	0	0		
	F	0	0	0	0		
curlleaf mountainmahogany/ bunchgrass	R	0	0	0	0	0	
	F	0	0	0	0	0	
curlleaf mountainmahogany/ pinegrass	R	0	0	0	0	0	
	F	0	0	0	0	0	
juniper/sagebrush/ bunchgrass	R	0	0	0	0	0	0
	F	0	0	0	0	0	0
curlleaf mountainmahogany/ shrub	R	0	0	0	0	0	0
	F	0	0	0	0	0	0
quaking aspen/grass	R	0	0	0	0	0	0
	F	2	2	2	2	2	2
quaking aspen/mountain big sagebrush/bunchgrass	R	0	0	0	0	0	0
	F	2	2	2	2	2	2
riparian	R	9	2	4	7	5	8
	F	9	4	4	7	6	8

These plant communities do not achieve a habitat form like that characterized by these structural conditions.

Appendix 5. 72 wildlife species found in southeast Oregon during migration or incidental in the area.

Letter code	Life form	Common name
		BIRDS
GAIM	3	common loon
POGRI	3	red-necked grebe[1]
POAU	3	horned grebe
PEERY	3	American white pelican[1]
PLCH	7	white-faced ibis[1]
OLCO	3	whistling swan
ANAL	3	white-fronted goose[1]
CHCA	3	snow goose
CHRO	3	Ross' goose
AYMA	3	greater scaup
BUCL	3	common goldeneye
BUALBE	14	bufflehead
SOSP	3	king eider
CLHY	3	oldsquaw
LOCU	14	hooded merganser
MESE	3	red-breasted merganser
BULA	4	rough-legged hawk
HALE	12	bald eagle[1]
FAPE	4	peregrine[1]
FACO	11	merlin[1]
CHSEM	3	semipalmated plover
CHMO	3	mountain plover[1]
TRSO	7	solitary sandpiper[1]
TRFL	3	lesser yellowlegs
CASE	3	willet[1]
CAMEL	3	pectoral sandpiper
CABA	3	Baird's sandpiper[1]
CAMI	3	least sandpiper
CAMAU	3	western sandpiper
LISC	3	long-billed dowitcher
LIFE	3	marbled godwit
LOLO	3	northern phalarope
LAAR	3	herring gull
LADE	3	ring-billed gull
LAPH	3	Bonaparte's gull
ARAL	7	black-chinned hummingbird
SEPL	7	broad-tailed hummingbird
SERUF	11	rufous hummingbird
EMHA	11	Hammond's flycatcher
NUBO	10	olive-sided flycatcher
PECA	11	gray jay
NUCO	10	Clark's nutcracker
PAGA	14	mountain chickadee
TRTR	3	winter wren
MIPO	7	northern mockingbird
IXNA	11	varied thrush
CAGU	5	hermit thrush
RESA	10	golden-crowned kinglet
ANSP	5	water pipet
BOGA	9	bohemian waxwing
LAEX	7	northern shrike
VISO	11	solitary vireo
OPTO	7	MacGillivray's warbler
SEAU	7	ovenbird
SERUT	9	American redstart
PHLU	9	rose-breasted grosbeak
PHME	11	black-headed grosbeak
PACY	8	indigo bunting
HEVE	11	evening grosbeak
CACAS	11	Cassin's finch
LEAT	4	black rosy finch
CAFL	9	common redpoll
CAPI	11	pine siskin
SPARB	11	American tree sparrow
ZOLE	7	white-crowned sparrow
ZOAT	7	golden-crowned sparrow
PAIL	7	fox sparrow
MELI	6	Lincoln's sparrow[1]
CALA	5	Lapland longspur
PLNI	5	snow bunting
		MAMMALS
LANO	14	silver-haired bat
LACI	9	hoary bat

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[1] Species of special interest; see appendix 13

Appendix 6. Wildlife orientation to plant communities by life form. Life form 1: reproduces in water; feeds in water. (2 species)

• – Primary (≥40%) reproduction and feeding
R – Primary (≥40%) reproduction only
F – Primary (≥40%) feeding only
0 – Secondary (<40%) reproduction and feeding
r – Secondary (<40%) reproduction only
f – Secondary (<40%) feeding only

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgr.	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper/sagebrush/bunchgr.	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	Number of plant communities used by each species for: R	F
	AMPHIBIANS																	R	F
RAPR	spotted frog																•	1	1
RACA	bullfrog								0								•	1	1
	R		0	0	0	0	0	0	0	0	0	0	0	0	0	0	2		
	F		0	0	0	0	0	0	0	0	0	0	0	0	0	0	2		

Appendix 6. Life form 2: reproduces in water; feeds on ground, in shrubs, and/or in trees. (6 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgr.	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper/sagebrush/bunchgr.	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	Number of plant communities used by each species for: R	F
	AMPHIBIANS																	R	F
AMMA	long-toed salamander			•			0										•	2	2
SCIN	Great Basin spadefoot toad	•		F	F			f	•	f	F	F	f	f	F	f	•	2	7
BUBO	western toad	f	F	F	F	f	r	f	•	F	f	f	f	f	F	F	•	2	8
BUWO	Woodhouse toad	F		F	F				f						F	F	•	1	5
HYRE	Pacific treefrog			•	F	0	0	0	•		0	0	0	0	F	F	•	3	6
RAPI	leopard frog			f				f	f						f	f	•	1	1
	R	1	0	2	0	0	0	0	3	0	0	0	0	0	0	0	6		
	F	2	1	5	4	0	0	0	3	1	1	1	0	0	4	3	6		

Appendix 6. Life form 3: reproduces on ground around water or on floating or emerging vegetation; feeds in water, on ground, in shrubs and trees. (44 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgr.	low sagebrush/bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany bunchgr	curlleaf mountainmahogany pinegr.	juniper sagebrush bunchgr	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for:	
	REPTILES																	R	F
THST	common garter snake		•	•	•	•	•	•	•		•	•	•	•	F	F	•	12	14
THEL	wandering garter snake			•	•			•	•	•			•		F	F	•	7	9
	BIRDS																		
POAU	horned grebe																•	1	1
PONIGR	eared grebe																•	1	1
AEOC	western grebe																•	1	1
POPO	pied-billed grebe																•	1	1
PHAU	double-crested cormorant						R		R								F	2	1
BOLE	American bittern			f													•	1	1
IXEX	least bittern			f													•	1	1
BRCA	Canada goose																•	1	1
ANPL	mallard			F	f	0		0	0								•	1	2
ANSTR	gadwall			F	f	0		0	0								•	1	2
ANAC	common pintail			F	f	0		0	0								•	1	2
ANCR	green-winged teal			F	f	0		0	0								•	1	2
ANDIS	blue-winged teal			F	f	0		0	0								•	1	2
ANCY	cinnamon teal			F	f	0		0	0								•	1	2
ANAMEO	American wigeon			F	f	0		0	0								•	1	2
ANCL	northern shoveler			F	f	0		0	0								•	1	2
AYAM	redhead																•	1	1
AYCO	ring-necked duck			F	f												•	1	2
AYVA	canvasback																•	1	1
AYAF	lesser scaup																•	1	1
OXJA	ruddy duck																•	1	1
GRCA	sandhill crane			•	F												•	2	3
RALI	Virginia rail			F	f												•	1	2
POCAR	sora			F	f												•	1	2
FUAM	American coot			f	f												•	1	1
CHALE	snowy plover			F	F												F	0	3
CHVO	killdeer			•	•												•	3	3
CAGA	common snipe			•	•												•	3	3
ACMA	spotted sandpiper			f	f												•	1	1
TRME	greater yellowlegs																•	1	1
REAM	American avocet			•	•												•	3	3
HIME	black-necked stilt			f													•	1	1
STTRI	Wilson's phalarope																•	1	1
LACA	California gull			F	F												•	1	3
LAPI	Franklin's gull			F	F												•	1	3

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgr.	low sagebrush bunchgrass	black greasewood grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper sagebrush/bunchgr.	curlleaf mountainmahogany/shrub	quaking aspen grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	Number of plant communities used by each species for:	
																		R	F
STFO	Forster's tern			f	f												●	1	1
STCAS	Caspian tern			f	f												●	1	1
CHNI	black tern			f	f												●	1	1
CIME	dipper																●	1	1
CIPA	marsh wren			f	f												●	1	1
GETR	common yellowthroat			f	f												●	1	1
XAXA	yellow-headed blackbird			f	f				0								●	1	1
	R	0	1	6	5	1	2	2	3	1	1	1	2	1	0	0	38		
	F	0	1	20	9	1	1	2	2	1	1	1	2	1	2	2	39		

Appendix 6. Life form 4: reproduces in cliffs, caves, talus, rims and/or talus; feeds on ground or in air. (33 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgr.	low sagebrush/bunchgrass	black greasewood grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany bunchgr	curlleaf mountainmahogany/pinegr.	juniper/sagebrush/bunchgr.	curlleaf mountainmahogany shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for:	
	REPTILES																	R	F
CRCO	collared lizard	0				●	●	●	●	●	●	●	●	●				9	9
SCOC	western fence lizard	0				0	0	0	●	●	●	●	●	●	0	0		6	6

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgr	low sagebrush bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountainmahogany bunchgr	curlleaf mountainmahogany pinegr	juniper sagebrush bunchgr	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for	
	BIRDS																	R	F
CAAU	turkey vulture	F	F	F	F	F	●	F	●	F	F	F	●	F	F	F	F	3	16
BUREG	ferruginous hawk	0		f	f	F	●	●	●	F	f	f	●	F	●	●	●	7	10
FAME	prairie falcon	●	f	F	F	F	●	●	F	f	f	f	F	f	f	F	F	3	10
ALCH	chukar					F	●	F	●	●	F	F	f	F	f	f	F	3	9
COLI	rock dove	F					●		R								●	3	3
CYNI	black swift	●	f	F	F	f	●	f	●	f	f	f	f	f	f	f	F	3	6
AESA	white-throated swift	●	f	F	F	f	●	f	●	f	f	f	f	f	f	f	●	4	6
SASA	Say's phoebe	f		F	F	f	F	f	f	f	●	●	●	●	●	●	F	6	10
HIRU	barn swallow	F	f	F	F	f	f	f	●	F	F	F	F	F	●	●	●	4	12
PEPY	cliff swallow	F	f	F	F	f	f	f	●	F	F	F	F	F	F	F	●	2	12
COCOR	common raven	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	16	16
CAMEXO	canyon wren	F				●	●	●	f		f	f					F	3	5
SAOB	rock wren	F					●	●	●		f	f					F	3	5
LEAT	black rosy finch	f	●	f	f	f	f										f	1	1
	MAMMALS																		
MYLU	little brown myotis			f	f				●				●		0	0	●	3	3
MYTH	fringed myotis												●				●	2	2
MYCA	California myotis			f	f			f	●				●		0	0	●	3	3
MYLE	small-footed myotis								●								●	2	2
PIHE	western pipistrelle								●				f				●	2	2
EPFU	big brown bat		f	f	f			f	●		f	f	●	f	0	0	●	3	3
EUMAC	spotted bat					●			0								●	2	2
PLTO	western big-eared bat								●								●	2	2
ANPA	pallid bat			f	f	f	f	f	●	f			●		f	f	●	3	3
MAFL	yellow-bellied marmot		●	●	0		●		●	●	●	●	●	●	●	●	●	12	12
PECR	canyon mouse								●				●				●	3	3
NELE	desert woodrat					●	●	●	●									4	4
NECI	bushy-tailed woodrat					F	F	F	●	F	F	F	●	F				2	9
ERDO	porcupine		f	f	f				●		●	●	●	●	f	f	●	6	6
SPPU	spotted skunk								●				●				●	3	3
FECO	cougar		F						●		●	●	●	●	F	F	F	5	9
LYRU	bobcat		F	F	F	●	●	●	●	●	●	●	●	●	●	●	●	12	15
	R	4	3	2	1	6	14	8	27	6	8	8	18	8	6	6	20		
	F	10	6	10	9	11	16	11	27	11	13	13	21	14	9	10	28		

Appendix 6. Life form 5: reproduces on ground without specific water, cliff, rim or talus association; feeds on ground. (45 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgr.	low sagebrush/bunchgrass	black greasewood grass	tall sagebrush/bunchgrass	squaw apple bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper/sagebrush/bunchgr.	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for:	
	REPTILES																	R	F
CRWI	leopard lizard					●	●	●	●	0	0	0	0	0				4	4
SCGR	sagebrush lizard						0	●	●	●	●	0	●	0				5	5
UTST	side-blotched lizard					●	●	●	●				●					5	5
PHPL	desert horned lizard	0				●	●	●	●	●	0	0	0	0				5	5
PHDO	short-horned lizard	0				0	●	0	●	0	0	0	●	0				3	3
EUSK	western skink							●	0	0			●	●			f	3	3
CNTI	western whiptail					●	●	●	●	0	0	0	●	●				6	6
CHBO	rubber boa						0		0		0	0	0	0	●		●	2	2
COCONS	yellow-bellied racer					0	●	●	●	0							●	4	4
MATA	striped whipsnake								●									1	1
PIME	gopher snake			●	0	0	0	●	●	0	0	0	●	0	0	0	●	5	5
HYTO	night snake					●	●		●				●					4	4
CRVI	western rattlesnake	●	●	●	●	●	●	●	●	●	●	●	●	●			●	14	14
	BIRDS																		
CICY	northern harrier	f	f	●	●	f	f	f	●	F	f	f	f	f			●	4	5
DEOB	blue grouse									f	f	f	●	●	●	●	●	5	5
BOUM	ruffed grouse									F	F	F	●	●	●	●	●	5	8
CEUR	sage grouse					F	●	F	●	f	f	f	F	F		F	F	2	8
LOCA	California quail								●	f	●	●	●	●	●	●	●	8	8
ORPI	mountain quail									f	F	F	●	●	f	F	F	2	6
PEPER	gray partridge	f		F	F		●	f	●	f	f	f	f	f			●	3	5
PHCOL	ring-necked pheasant			f	f		f		●	f		f	f	f	f		●	2	2
NUAM	long-billed curlew	f		F	F	●	●	f	●								●	4	6
ASFL	short-eared owl		f	●	●		f	f	●		F	F	F	F			●	4	8
ERAL	horned lark	●	f	F	F	f	●	0	●	0	F	F	f				f	3	7
CAFU	veery			f	f						f	f			0	0	●	1	1
WIPU	Wilson's warbler			f	f				f	f	f				●	●	●	3	3
DOOR	bobolink			●	●												●	3	3
STNEG	western meadowlark	F	f	F	F		●	0	●	●	0	0	●	0	●	●	F	6	10
PASA	savannah sparrow	f		f	f		●		0	F	F		F	f	f	f	f	1	4
AMSA	grasshopper sparrow	f		f	f		●		0	F	F		F	f	f	f	f	1	4
POGRA	vesper sparrow	f		f	f		●		0	F	F		F	f	f	f	f	1	4
CHGR	lark sparrow	f		F	F		●		●	f	F	F	F	F	●	●	●	5	11
JUHY	northern junco			F	F	●	●	●	●	●	●	●	●	●	●	●	●	12	14

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgr	low sagebrush bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountainmahogany bunchgr	curlleaf mountainmahogany pinegr	juniper sagebrush bunchgr	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for	
	MAMMALS																	R	F
SYID	pygmy rabbit					●	●	●	●				●					5	5
SYNU	mountain cottontail					0	●	●	●	0	●	●	●	●			●	8	8
LETO	white-tailed jackrabbit	F	F	F	f				●	F	F	F	F	F			F	1	10
LECA	black-tailed jackrabbit	F	F	F	F	F	●	F	●	F	F	F	F	F			F	2	14
RARA	black rat								●						●	●	●	4	4
RANO	Norway rat								●						●	●	●	4	4
FECA	feral house cat							●					●		F	F	●	3	5
EQUA	feral horse			●	●	0	0	F	●	0	0	0	●	0	0	0	0	4	5
CEEL	elk										F	F	F	F	●	●	●	3	7
ODHE	mule deer	f	F	F	F	F	F	F	●	F	●	●	●	●	f	F	F	5	14
ANAMER	pronghorn	●				F	●	F	●	F	F	F	F	F			F	3	11
OVCA	bighorn sheep	f	F	F	F	F	F	f	F	f	●	●	f	●	f	f	F	3	10
	R	3	1	6	5	9	22	13	31	5	7	6	19	11	11	10	22		
	F	6	5	16	14	14	24	18	32	14	19	15	29	17	13	14	30		

Appendix 6. Life form 6: reproduces on ground; feeds in shrubs, trees, or air. (4 species)

Letter code	Species		crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgr.	low sagebrush bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper/sagebrush/bunchgr.	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for: R	F
	BIRDS																		R	F
PHNU	poorwill		f		F	F	F	●	F	●	F	f	f	f	f	f	f	F	2	8
CHMI	common nighthawk			f	F	F	F	●	F	●	F	●	F	●	F	F	●	F	5	14
MYTO	Townsend's solitaire						F	F	F	●	F	F	F	●	●	F	●	F	4	12
VECE	orange-crowned warbler															●	●	●	3	3
		R	0	0	0	0	0	2	0	3	0	1	0	2	1	1	3	1		
		F	0	0	2	2	3	3	3	3	3	2	2	2	2	3	3	4		

Appendix 6. Life form 7: reproduces in shrubs; feeds on ground, in water or air. (29 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgr.	low sagebrush bunchgrass	black greasewood grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany bunchgr.	curlleaf mountainmahogany/pinegr.	juniper sagebrush/bunchgr.	curlleaf mountainmahogany shrub	quaking aspen/grass	quaking aspen mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for: R	F
	BIRDS																	R	F
BUST	green heron																●	1	1
BUIB	cattle egret	f		F	F				0						●	●	●	3	5
NYNY	black-crowned night heron			F	F				0						●	●	●	3	5
BUSW	Swainson's hawk			f	f	f	F	F	●	f	F	F	●	F	●	●	●	5	10
STCAL	calliope hummingbird			F	F								●	●	●	●	●	5	7
CAAN	Anna's hummingbird			F	F								●	●	●	●	●	5	7
TYTY	eastern kingbird						f	f	●	f	F	F	●	●	●	●	●	6	8
EMTR	willow flycatcher					F	F	F	F	F	F	F	F	F	●	●	●	3	12
EMWR	gray flycatcher					F	F	F	●	F	●	●	●	●	●	●	F	7	12
APCO	scrub jay			F	F		f	f	●	f	●	●	●	●	F	F	●	6	10
PIPI	black-billed magpie	F	F	F	F	F	F	F	●	●	●	●	●	●	●	●	●	9	16

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgr.	low sagebrush bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountainmahogany bunchgr.	curlleaf mountainmahogany pinegr.	juniper sagebrush bunchgr	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for	
																		R	F
DUCA	gray catbird						f	f	F	F	F	F	F	F	•	•	•	3	9
TORV	brown thrasher					f	•	F	•	F	F	F	•	•	F	•	•	6	11
ORMO	sage thrasher						F	F	•	F	f	f	•	•	f	•	f	4	7
TUMI	American robin			F	F				f		F	F	F	F	•	•	•	3	9
CAUS	Swainson's thrush						f	f	•	f	F	F	F	F	•	•	•	4	8
PACAE	blue-gray gnatcatcher								•	f	f	f	•	F	F	•	F	3	6
LALU	loggerhead shrike					F	F	•	•	F	F	F	•	•	F	F	•	5	12
AGPH	red-winged blackbird			•	•	F	F	F	•	F	F	F	F	F	•	•	•	6	14
EUCY	Brewer's blackbird	f		•	•	F	F	F	•	F	F	F	•	F	•	•	•	7	14
MOAT	brown-headed cowbird	f		•	•	F	F	F	•	F	F	F	•	F	•	•	•	7	14
PAAMO	lazuli bunting								f	f	f	f	f	F	•	•	•	3	4
CAPS	lesser goldfinch								f	F	F	F	F	•	•	•	•	4	8
PICH	green-tailed towhee					F	F	F	•	•	•	•	F	•	F	•	f	6	11
PIER	rufous-sided towhee					f	f	f	•	F	F	F	•	•	•	•	•	6	9
AMBE	sage sparrow						•	f	•	f	f	f	•	•	f	•	f	5	5
SPPA	chipping sparrow							f	F	F	F	F	•	•	•	•	•	5	9
SPBRE	Brewer's sparrow						•	f	•	f	f	f	•	F	f	•	f	4	5
NEMEL	song sparrow					F	•	F	•	F	F	F	•	F		F	•	4	11
	R	0	0	3	3	0	4	1	18	2	4	4	18	14	19	25	23		
	F	1	1	10	10	9	14	12	21	15	19	19	25	26	24	28	25		

Appendix 6. Life form 8: reproduces in shrubs; feeds in shrubs, trees, or air. (5 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgr	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper/sagebrush/bunchgr.	curlleaf mountainmahogany/shrub	quaking aspen grass	quaking aspen mountain big sagebrush/bunchgrass	riparian	Number of plant communities used by each species for:	
	BIRDS																	R	F
COAM	yellow-billed cuckoo																●	1	1
PSMI	bushtit					F	F	F	●	F	F	F	●	●	F	●	●	5	12
DEPE	yellow warbler					f	f	f	F	F	F	F	F	F	f	●	●	2	8
ICVI	yellow-breasted chat								F	F	F	F	f	●	f	●	●	3	7
CATR	American goldfinch					f	f	f	F	F	F	F	F	●	●	●	●	4	9
	R	0	0	0	0	0	0	0	1	0	0	0	1	3	1	4	5		
	F	0	0	0	0	1	1	1	4	4	4	4	3	4	2	4	5		

Appendix 6. Life form 9: reproduces primarily in deciduous trees; feeds in shrubs, trees, or air. (3 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgr.	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr	curlleaf mountainmahogany/pinegr.	juniper/sagebrush/bunchgr.	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for:	
	BIRDS																	R	F
BOCE	cedar waxwing												F	F	●	●	●	3	5
ICGA	northern oriole												F		●	●	●	3	4
CAMEXI	house finch					f	f	f	F	F	F	F	●	●	●	●	●	5	9
	R	0	0	0	0	0	0	0	0	0	0	0	1	1	3	3	3		
	F	0	0	0	0	0	0	0	1	1	1	1	3	2	3	3	3		

Appendix 6. Life form 10: reproduces primarily in conifers; feeds in shrubs, trees, or air. (7 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm wet meadows	seasonally wet meadows	shadscale saltbush bunchgr.	low sagebrush bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountainmahogany bunchgr	curlleaf mountainmahogany pinegr	juniper sagebrush bunchgr	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for	
	BIRDS																	R	F
EMDI	western flycatcher						f	f	F	F	F	F	●	●	F	●	●	4	9
GYCY	pinyon jay								F	F	F	F	●	F	F	F	F	1	9
RECA	ruby-crowned kinglet								f	f	f	f	f	f	●	●	●	3	3
DECOR	yellow-rumped warbler								f	f	f	f	●	F	●	●	●	4	5
DENI	black-throated gray warbler								f	f	f	f	F	F	F	●	F	1	5
DETO	Townsend's warbler								f	f	f	f	f	f	f	f	●	1	1
PILU	western tanager								f	f	f	f	F	f	●	●	●	3	4
	R	0	0	0	0	0	0	0	0	0	0	0	3	1	3	5	5		
	F	0	0	0	0	0	0	0	2	2	2	2	5	4	6	6	7		

Appendix 6. Life form 11: reproduces in trees; feeds on ground, in shrubs, trees, or air. (13 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgr.	low sagebrush bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountainmahogany bunchgr	curlleaf mountainmahogany pinegr	juniper sagebrush bunchgr	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for	
	BIRDS																	R	F
ACGE	northern goshawk														●	F	●	2	3
ACST	sharp-shinned hawk			f	f				f	f	f	f	F	f	●	●	●	3	4
ACCO	Cooper's hawk			f	f				0	F	F	F	F	F	●	●	●	3	8
ZEMA	mourning dove	F	F	F	F	F	●	●	●	F	●	●	●	●	●	●	●	10	16
ASOT	long-eared owl								f	f	f	f	F	f	●	●	●	3	4
TYVE	western kingbird			f	f		f	f	●	F	F	F	F	F	●	●	●	4	9
COSO	western wood pewee						f	f	F	F	F	F	F	F	●	●	●	3	9
CYST	Steller's jay								F	F	F	F	●	●	●	●	●	5	9

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgr.	low sagebrush/bunchgrass	black greasewood grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper sagebrush/bunchgr.	curlleaf mountainmahogany/shrub	quaking aspen grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	Number of plant communities used by each species for:	
																		R	F
COBRA	American crow	f	f	F	F	F	F	F	●	F	F	F	●	F	●	●	●	5	14
VIOL	red-eyed vireo														●	●	●	3	3
VIGI	warbling vireo														●	●	●	3	3
CAPU	purple finch	f	F	F	F	f	f	f	F	f	F	F	●	F	●	●	●	4	11
SPARB	American tree sparrow	f	F	F	F	f	f	f	F	f	F	F	●	F	●	●	●	4	11
	R	0	0	0	0	0	1	1	3	0	1	1	5	2	13	12	13		
	F	1	3	4	4	2	2	2	7	6	8	8	10	8	13	13	13		

Appendix 6. Life form 12: reproduces on very thick branches; feeds on ground or in water. (6 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgr.	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany bunchgr.	curlleaf mountainmahogany pinegr.	juniper sagebrush/bunchgr.	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	Number of plant communities used by each species for:	
	BIRDS																	R	F
ARHE	great blue heron	f		F	F				0				R		R	R	●	4	3
CAAL	common egret	f		F	F				0				R		R	R	●	4	3
BUJA	red-tailed hawk	f	f	F	F	F	F	F	●	F	F	F	●	●	●	●	●	6	14
AQCH	golden eagle	F	F	F	F	F	F	F	●	F	F	F	●	●	F	F	●	4	16
PAHA	osprey																●	1	1
BUVIR	great horned owl	f	F	F	F	F	F	F	●	F	F	F	●	●	●	●	●	6	15
	R	0	0	0	0	0	0	0	3	0	0	0	5	3	4	4	6		
	F	1	2	5	5	3	3	3	3	3	3	3	3	3	3	3	6		

Appendix 6. Life form 13: reproduces – excavates own hole in a tree; feeds on ground, in shrubs, trees, or air. (9 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm wet meadows	seasonally wet meadows	shadscale saltbush bunchgr	low sagebrush bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountainmahogany bunchgr	curlleaf mountainmahogany pinegr	juniper sagebrush bunchgr	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for	
	BIRDS																	R	F
COAU	common flicker					F	F	F	F	F	F	F	●	F	●	●	●	4	12
MELE	Lewis' woodpecker								f	f	f	f	0	f	●	●	●	3	3
SPVAR	yellow-bellied sapsucker												●		●	●	●	4	4
SPTH	Williamson's sapsucker												●		●	●	●	4	4
PIVI	hairy woodpecker												●		●	●	●	4	4
PIPU	downy woodpecker														●	●	●	3	3
PIAL	white-headed woodpecker														F	F	●	1	3
SICAR	white-breasted nuthatch												●		F	F	F	1	4
SICAN	red-breasted nuthatch												●		F	F	●	2	4
	R	0	0	0	0	0	0	0	0	0	0	0	6	0	6	6	8		
	F	0	0	0	0	1	1	1	1	1	1	1	6	1	9	9	9		

Appendix 6. Life form 14: reproduces in hole made by another species or that has occurred naturally; feeds on ground, in water, or air. (25 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgr.	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper/sagebrush/bunchgr.	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	Number of plant communities used by each species for:	
	BIRDS																	R	F
AISP	wood duck																●	1	1
BUIS	Barrow's goldeneye																●	1	1
MEMER	common merganser																●	1	1
FASP	American kestrel			F	F		F		F				●		●	●	●	4	8
TYAL	barn owl			F	F		F		F								●	1	5
OTAS	common screech owl			F	F		F		F				●	F	●	●	●	4	9
OTFL	flammulated owl														●	●		2	2
GLGN	pygmy owl			F	F		F		F				●	F	●	●	●	4	9
AEAC	saw-whet owl			f	f		f		f						●	●	●	3	3
CHVA	Vaux's swift			F	F	f	f	f	F	f	f	F	f	F	0	0	●	1	6
MYCI	ash-throated flycatcher			F	F	f	F	f	F	f	f	F	●	F	●	●	●	4	10
TATH	violet-green swallow			F	F		f		f			f		f	●	●	●	3	5
IRBI	tree swallow			F	F		f		f			f		f	●	●	●	3	5
PAATR	black-capped chickadee								f			F	●	F	●	●	●	4	6
CEFA	brown creeper								f			F	●	F	●	●	●	4	6
TRAE	house wren								F			f	●	●	●	●	●	5	6
SIME	western bluebird	f	f	F	F	F	F	F	F	F	F	F	●	F	●	●	●	4	14
SICU	mountain bluebird	f	f	F	F	F	F	F	F	F	F	F	●	F	●	●	●	4	14
STVU	European starling	f		F	F	f	f	f	F	F	f	f	●	f	●	●	●	4	8
PADO	house sparrow			F	F	f	f	f	F	f	f	f	f	f	●	●	●	3	6
	MAMMALS																		
MYYU	Yuma myotis					F	F	F	F	F	F	F	F	F			●	1	10
MYEV	long-eared myotis					F	F	F	F	F	F	F	F	F			●	1	10
MYVO	long-legged myotis					F	F	F	F	F	F	F	F	F			●	1	10
LANO	silver-haired bat					F	F	F	F	F	F	F	F	F			●	1	10
PRLO	raccoon								f				f				●	1	1
	R	0	0	0	0	0	0	0	0	0	0	0	10	1	15	15	24		
	F	0	0	12	12	6	11	6	15	7	6	10	14	13	15	15	24		

Appendix 6. Life form 15: reproduces – underground burrow; feeds on or near ground. (32 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgr.	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple bunchgrass	curlleaf mountainmahogany bunchgr	curlleaf mountainmahogany pinegr.	juniper/sagebrush bunchgr.	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	Number of plant communities used by each species for:	
	REPTILES																	R	F
SOSE	western ground snake					●	●	●	●									4	4
	BIRDS																		
ATCU	burrowing owl	●	f	F	F	●	●	F	●	F	f	f	f	f			F	4	9
	MAMMALS																		
SOME	Merriam shrew						●		●				●					3	3
EUMI	least chipmunk					0	●	●	●		●	●	0	●				6	6
EUQM	yellow pine chipmunk								●				●					2	2
AMLE	antelope ground squirrel					●		●										2	2
SPTO	Townsend ground squirrel	●			●				●								●	4	4
SPRI	Richardson ground squirrel								●									1	1
SPBE	Belding ground squirrel		●	●	0		●		●								●	5	5
SPCO	Columbian ground squirrel			●														1	1
SPLA	mantled ground squirrel						●		●		●	●	●	●				6	6
THTO	Townsend pocket gopher	●		●	●	●	●	●	●								●	8	8
THTA	northern pocket gopher	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	16	16
PELO	little pocket mouse					●												1	1
PEPA	Great Basin pocket mouse	0				●	●	●	●	0	0	0	●	0				5	5
MIME	dark kangaroo mouse					●												1	1
DIOR	Ord kangaroo rat	0				●		●	●									3	3
DIMI	chisel-toothed kangaroo rat					●		●	0									2	2
REME	western harvest mouse							●	●	●	0	0	●	0			●	5	5
PEMA	deer mouse	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	16	16
ONLE	northern grasshopper mouse					0	0		●				●					2	2
MIMO	montane vole		●	●	0			0	●				0		0	0	●	4	4
MILO	long-tailed vole		●	●	●			0	●				●				●	6	6
LACU	sage vole	●	●				●		●				●					5	5
ZAPR	western jumping mouse		●	●													●	3	3
CALAT	coyote	●	●	●	●	●	●	●	●	●	●	●	●	●			●	14	14
VUVU	red fox																●	1	1
VUMA	kit fox					●	●	●										3	3
MUER	short-tailed weasel		0														●	1	1
MUFR	long-tailed weasel	●	●	●	●	0	0	0	●	0	●	●	●	●	0	0	●	10	10
TATA	badger	f	0	f	f	f	●	f	●	f	f	f	●	f	f	f	●	4	4
MEMEP	striped skunk								●								●	2	2
	R	8	9	10	7	13	14	12	23	4	6	6	13	6	2	2	15		
	F	8	9	11	8	13	14	13	23	5	6	6	13	6	2	2	16		

Appendix 6. Life form 16: reproduces – underground burrow; feeds in water, on ground, or in air. (9 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgr.	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper sagebrush/bunchgr.	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	Number of plant communities used by each species for:	
	BIRDS																	R	F
MEAL	belted kingfisher																●	1	1
RIRI	bank swallow		f	F	F		f	f	F	f	f	f	f	f	F	F	●	1	6
STRU	rough-winged swallow		f	F	F		f	f	F	f	f	f	f	f	F	F	●	1	6
	MAMMALS																		
SOPR	Malheur shrew		●	●													●	3	3
SOVA	wandering shrew		●	●					●								●	4	4
CACAN	beaver																●	1	1
ONZI	muskrat																●	1	1
MUVI	mink								f								●	1	1
LUCA	river otter																●	1	1
	R	0	2	2	0	0	0	0	1	0	0	0	0	0	0	0	9		
	F	0	2	4	2	0	0	0	3	0	0	0	0	0	2	2	9		

Appendix 7. Wildlife orientation to structural conditions by life form. Life form 1: reproduces in water; feeds in water. (2 species)

• – Primary (≥40%) reproduction and feeding

0 – Secondary (<40%) reproduction and feeding

R – Primary (≥40%) reproduction only

r – Secondary (<40%) reproduction only

F – Primary (≥40%) feeding only

f – Secondary (<40%) feeding only

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	R	F
	AMPHIBIANS																	
RAPR	spotted frog		•			•			•			•			•		5	5
RACA	bullfrog		•			•			•			•			•		5	5
	R	2	2	0	0	2	0	0	2	0	0	2	0	0	2	0		
	F	2	2	0	0	2	0	0	2	0	0	2	0	0	2	0		

Appendix 7. Life form 2: reproduces in water; feeds on ground, in shrubs, and/or trees. (6 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
		bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	R	F
	AMPHIBIANS																	
AMMA	long-toed salamander		•		R	F		R	F							•	4	3
SCIN	Great Basin spadefoot toad		•	F	•	F	F	•	F	F	R	F	F				4	10
BUBO	western toad		F	F	R	F		R	F		R	F	F		•	•	5	8
BUWO	Woodhouse toad		F	f	R	F		R	F		R	F	F		•		4	6
HYRE	Pacific treefrog		•	F	•	F	•	•	F	•	•	F	•	•	F	•	9	13
RAPI	leopard frog				R	F	F	R	F	F	R	F	F				3	6
	R	0	3	0	6	0	1	6	0	1	5	0	1	1	2	3		
	F	0	5	3	2	6	3	2	6	3	1	5	5	1	3	3		

Appendix 7. Life form 3: reproduces on ground around water or on floating or emergent vegetation; feeds in water, on ground, in shrubs, and trees. (44 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	REPTILES																R	F
THST	common garter snake	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	15	15
THEL	wondering garter snake	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	15	15
	BIRDS																	
POAU	horned grebe	F			F	R		F	R		F			F	R		3	5
PONIGR	eared grebe	F			F	R		F	R		F			F	R		3	5
AEOC	western grebe		R			R			R						R		4	0
POPO	pied-billed grebe	F	R		F	R		F	R		F	R		F	R		5	5
PHAU	double-crested cormorant				R	R	R	R	R	R							6	0
BOLE	American bittern	F	●		F	●		F	●		F	●		F	●		5	10
IXEX	least bittern	F	●		F	●		F	●		F	●		F	●		5	10
BRCA	Canada goose		●	f		●	f										2	2
ANPL	mallard		F			●	●		●	●		0	●		●	●	7	8
ANSTR	gadwall		F			●	●		●	●		0	●		●	●	7	8
ANAC	common pintail		F			●	●		●	●		0	●		●	●	7	8
ANCR	green-winged teal		F			●	●		●	●		0	●		●	●	7	8
ANDIS	blue-winged teal		F			●	●		●	●		0	●		●	●	7	8
ANCY	cinnamon teal		F			●	●		●	●		0	●		●	●	7	8
ANAMEO	American wigeon		F			●	●		●	●		0	●		●	●	7	8
ANCL	northern shoveler		F			●	●		●	●		0	●		●	●	7	8
AYAM	redhead		●														1	1
AYCO	ring-necked duck		F			●	0		0	0		0	0		●	0	2	3
AYVA	canvasback		●														1	1
AYAF	lesser scaup		F												●		1	2

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	R	F
OXJA	ruddy duck		F												●		1	2
GRCA	sandhill crane		●			F											1	2
RALI	Virginia rail		F			●	f		●	f			f		●	f	3	4
POCAR	sora		F			●			●						●		3	4
FUAM	American coot		F			●			●			0			●		3	4
CHALE	snowy plover	●	F														1	2
CHVO	killdeer	●	●		●	f		●	f		●	f		●	f		6	6
CAGA	common snipe	F	●	f		●			●			0			0		3	4
ACMA	spotted sandpiper	F	●	●	F	●	f	F	●	f							4	7
TRME	greater yellowlegs		●														1	1
REAM	American avocet	F	●	f	F	f	f	F	f	f							1	4
HIME	black-necked stilt	F	●		F	●		F	●								3	6
STTRI	Wilson's phalarope	F	●		F	●		F	●								3	6
LACA	California gull	F	●	F	F	●	f	f	f	f	f	f	f	f	f	f	2	5
LAPI	Franklin's gull	F	●	F	F	●	f	f	f	f	f	f	f	f	f	f	2	5
STFO	Forster's tern	F	●	F	F	●											2	5
STCAS	Caspian tern	F	●	F	F	●											2	5
CHNI	black tern	F	●	F	F	●											2	5
CIME	dipper	F	●		F	●		F	●					●	●	F	5	9
CIPA	marsh wren		●			●			●			●			●		5	5
GETR	common yellowthroat		F		F	●		F	●			F			F		2	7
XAXA	yellow-headed blackbird		●			●			●			0			●		4	4
	R	4	25	3	4	35	11	4	28	11	3	6	10	4	25	10		
	F	20	39	8	19	30	10	14	23	10	8	6	10	9	22	11		

Appendix 7. Life form 4: reproduces on cliffs, caves, rims and/or talus; feeds on ground or in air. (33 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/ shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	REPTILES																R	F
CRCO	collared lizard	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	15	15
SCOC	western fence lizard	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	15	15
	BIRDS																	
CAAU	turkey vulture	●	F	F	●	F	F	●	F	F	●	F	F	●	F	F	5	15
BUREG	ferruginous hawk	f	F	●	f	●	●	f	●	●	f	●	●	f	●	●	9	10
FAME	prairie falcon	f	●	●	f	●	●	f	●	●	f	●	●	f	●	●	10	10
ALCH	chukar	f	F	●	f	F	●	f	F	●	f	F	F	f	F	F	3	10
COLI	rock dove		●	R		●	R		F	F		F	F		F	F	4	8
CYNI	black swift	f	F	●	f	F	●	f	F	●	f	F	●	f	F	●	5	10
AESA	white-throated swift	f	F	●	f	F	●	f	F	●	f	F	●	f	F	●	5	10
SASA	Say's phoebe		F	●		F	●		F	●		F	●		F	●	5	10
HIRU	barn swallow		F	●		F	●		F	●		F	●		F	●	5	10
PEPY	cliff swallow		F	●		F	●		F	●		F	●		F	●	5	10
COCOR	common raven	F	●	●	F	●	●	F	●	●	F	●	●	F	●	●	10	15
CAMEXO	canyon wren		●	●		●	●		●	●		●	●		●	●	10	10
SAOB	rock wren		●	●		●	●		●	●		●	●		●	●	10	10
LEAT	black rosy finch		●	●		F	F		F	F		F	F		F	●	3	10
	MAMMALS																	
MYLU	little brown myotis		●	●		●	●		●	●	F	●	●	F	●	●	10	12
MYTH	fringed myotis		●	●		●	●		●	●	F	●	●	f	●	●	10	11
MYCA	California myotis		●	●		●	●		●	●	f	●	●	F	●	●	10	11
MYLE	small-footed myotis		●	●		●	●		●	●	f	●	●	f	●	●	10	10
PIHE	western pipistrelle		●	●		●	●		●	●	f	●	●	F	●	●	10	11
EPFU	big brown bat		●	●		●	●		●	●	F	●	●	f	●	●	10	11
EUMAC	spotted bat	f	●	●	f	●	●										4	4
PLTO	western big-eared bat		●	●	F	●	●	F	●	●	f	●	●	F	●	●	10	13
ANPA	pallid bat		●	●	F	●	●	F	●	●	f	●	●	f	●	●	10	12
MAFL	yellow-bellied marmot		●	●		0	0		●	●		0	0		0	0	4	4
PECR	canyon mouse	●	●	●		0	0	f	●	●	●	●	●	●	●	●	11	11
NELE	desert woodrat	●	●	●		0	0		●	●	●	●	●	●	●	●	11	11
NECI	bushy-tailed woodrat	●	●	●		0	0		●	●	●	●	●	●	●	●	11	11
ERDO	porcupine		F	F		f	f		F	F		●	●		●	●	4	8
SPPU	spotted skunk	●	●	●	0	0	0	●	●	●	F	●	●	F	●	●	10	12

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/ shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	R	F
FECO	cougar	f	f	f	f	f	f	f	•	•	f	•	•	f	•	•	6	6
LYRU	bobcat	f	f	f	f	f	f	f	•	•	f	•	•	f	•	•	6	6
	R	7	22	29	3	17	23	4	22	28	6	22	27	6	22	28		
	F	8	31	30	6	25	24	7	32	32	11	31	31	12	31	31		

Appendix 7. Life form 5: reproduces on ground without specific water, cliff, rim or talus association; feeds on ground. (45 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	R	F
	REPTILES																R	F
CRWI	leopard lizard	•	•	0	•	•	0	•	•	0	•	0	0	•	0	0	8	8
SCGR	sagebrush lizard				F	•	•	F	•	•	f	•	•	f	•	•	8	10
UTST	side-blotched lizard	F		F	F	•	•	F	•	•	F	•	•	F	•	•	8	14
PHPL	desert horned lizard	F		•	f	•	•	f	•	•	f	•	•	f	f	0	7	8
PHDO	short-horned lizard	F		•	f	•	•	f	•	•	f	•	•	f	•	0	7	8
EUSK	western skink			0		F	•		F	•		F	•		F	•	4	8
CNTI	western whiptail	0	0		•	•	0	•	•	0	•	0	0	•	0	0	6	6
CHBO	rubber boa				f	•	•	f	•	•	F	•	•	F	•	•	8	10
COCONS	yellow-bellied racer		0	0	f	•	•	f	•	•	f	•	•	f	•	•	8	8
MATA	striped whipsnake		F	F		•	•		•	•		•	•		•	•	8	10
PIME	gopher snake		F	0	F	•	•	F	•	•		0	0		0	0	4	7
HYTO	night snake	•	F		•	F		•	F		•	F		•	F		5	10

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	R	F
CRVI	western rattlesnake		F	●		F	●		F	●		F	●		F	●	5	10
CICY	northern harrier		●	0		●	F								●	F	3	5
DEOB	blue grouse					●	F		●	F					●	F	3	6
BOUM	ruffed grouse					●	F		●	F		●	F		●	F	4	8
CEUR	sage grouse					●	●		●	●		●	●		●	●	8	8
LOCA	California quail					●			●						●		3	3
ORPI	mountain quail					●	F		●	F		●	F		●	F	4	8
PEPER	gray partridge	F	●	F	F	●	F										2	6
PHCOL	ring-necked pheasant		●			●			●						●		4	4
NUAM	long-billed curlew		●	●		●	●		●	●		F	F		F	F	6	10
ASFL	short-eared owl		●	F		●	F		F	F		F	F		F	F	2	10
ERAL	horned lark	●	●	●	●	F	●		F	F		F	F				5	10
CAFU	veery					●			●						●		3	3
WIPU	Wilson's warbler					●			●						●		3	3
DOOR	bobolink		●			●			●			●			●		5	5
STNEG	western meadowlark		●	●		F	F		F	F		F	F		F	F	2	10
PASA	savannah sparrow		●	●		●	●		F	F		F	F		F	F	4	10
AMSA	grasshopper sparrow		●	●		●	●		F	F		F	F		F	F	4	10
POGRA	vesper sparrow		●	●		●	●		F	f							4	6
CHGR	lark sparrow		F	F		F	●		●	●		F	F		F	●	4	10
JUHY	northern junco		F	F		●	●		●	●		●	●		●	●	8	10
	MAMMALS																	
SYID	pygmy rabbit					f	0		●	●					●	●	4	4
SYNU	mountain cottontail					0	0		●	●		0	0		●	●	4	4
LETO	white-tailed jackrabbit		F	F		f	●		●	●	f	F	F	f	●	●	5	9
LECA	black-tailed jackrabbit		F	F		f	0		●	●	f	F	F	f	●	●	4	8
RARA	black rat					0	0		●	●					●	●	4	4
RANO	Norway rat					0	0		●	●					●	●	4	4
FECA	feral house cat		F	F		F	F		●	●		F	F		●	●	4	10
EQUA	feral horse		●	●		0	0		●	●		●	●		●	●	8	8
CEEL	elk					f	f		f	f		F	F		●	●	2	4
ODHE	mule deer		F	F		F	0		F	●		F	F		F	●	2	9
ANAMER	pronghorn		F	F		F	●		F	●		F	F		F	●	3	10
OVCA	bighorn sheep		F	●		F	0		F	●		F	●		F	F	3	9
	R	3	14	12	4	27	20	3	30	25	3	13	13	3	26	21		
	F	7	25	22	8	37	28	6	42	34	5	30	28	5	38	31		

Appendix 7. Life form 6: reproduces on ground; feeds in shrubs, trees, or air. (4 species)

Structural conditions

Letter code	Species	Grass-forb			Low shrub			Tall shrub			Tree			Tree shrub				
		bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	BIRDS																R	F
PHNU	poorwill		F	F	F	●	F	F	●	F							2	8
CHMI	common nighthawk	f	F	F	F	●	●	F	●	●	F	●	●	F	●	●	8	14
MYTO	Townsend's solitaire					●	●		●	●		●	●		●	●	8	8
VECE	orange-crowned warbler					●			●			●			●		4	4
	R	0	0	0	0	4	2	0	4	2	0	3	2	0	3	2		
	F	0	2	2	2	4	3	2	4	3	1	3	2	1	3	2		

Appendix 7. Life form 7: reproduces in shrubs; feeds on ground, in water or air. (29 species)

Structural conditions

Letter code	Species	Grass-forb			Low shrub			Tall shrub			Tree			Tree/ shrub				
		bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	BIRDS																R	F
BUST	green heron		F	F		F	F							R	R	R	3	4
BUIB	cattle egret		F						●			●			●		3	4
NYNY	black-crowned night heron								●			●			●		3	3
BUSW	Swainson's hawk		F	F		F	F		●	●		●	●		●	●	6	10
STCAL	calliope hummingbird		F			F			●			●			●		3	5
CAAN	Anna's hummingbird		F						●			●			●		3	4
TYTY	eastern kingbird						F		●	F		●	F		●	F	3	7

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	R	F
EMTR	willow flycatcher					F	F		●	●		●	●		●	●	6	8
EMWR	gray flycatcher								●	●		●	●		●	●	6	6
APCO	scrub jay								●	●		F	F		●	●	4	6
PIPI	black-billed magpie		F	F		F	F		●	●		●	●		●	●	6	10
DUCA	gray catbird					F	F		●	●		f	f		●	●	4	6
TORV	brown thrasher					F	F		●	●					●	●	4	6
ORMO	sage thrasher								●	●					●	●	4	4
TUMI	American robin		F			F	f		●	●		●	●		●	●	6	8
CAUS	Swainson's thrush								●	●		F	F		●	●	4	6
PACAE	blue-gray gnatcatcher								●	●		●	●		●	●	6	6
LALU	loggerhead shrike					F	F		F	●		●	●		●	●	5	8
AGPH	red-winged blackbird		●			●			●			●			●		5	5
EUCY	Brewer's blackbird		●			●			●			●			●		5	5
MOAT	brown-headed cowbird		●			●			●			●	●		●	●	7	7
PAAMO	lazuli bunting								●	●		F	F		●	●	4	6
CAPS	lesser goldfinch					F	F		●	●		F	F		F	F	2	8
PICH	green-tailed towhee					●	●		●	●					●	●	6	6
PIER	rufous-sided towhee					●	●		●	●					●	●	6	6
AMBE	sage sparrow								●	●		F	F		●	●	4	6
SPPA	chipping sparrow								●	●		●	●		●	●	6	6
SPBRE	Brewer's sparrow					●	●		●	●		F	F		●	●	6	8
NEMEL	song sparrow								●	●					●	●	4	4
	R	0	3	0	0	6	3	0	27	20	0	16	9	1	28	21		
	F	0	10	3	0	16	12	0	28	21	0	22	16	0	28	22		

Appendix 7. Life form 8: reproduces in shrubs; feeds in shrubs, trees, or air. (5 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	BIRDS																R	F
COAM	yellow-billed cuckoo								●	●		0	0		●	●	4	4
PSMI	bushtit					F	F		●	●	f	F	F	f	●	●	4	8
DEPE	yellow warbler								●	●		●	●		●	●	6	6
ICVI	yellow-breasted chat								●	●					●	●	4	4
CATR	American goldfinch					F	F		●	●		●	●		●	●	6	8
	R	0	0	0	0	0	0	0	5	5	0	2	2	0	5	5		
	F	0	0	0	0	2	2	0	5	5	0	3	3	0	5	5		

Appendix 7. Life form 9: reproduces primarily in deciduous trees; feeds in shrubs, trees, or air. (3 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	BIRDS																R	F
BOCE	cedar waxwing								●	0	0	F	F	0	●	●	3	5
ICGA	northern oriole					f	f		●	F		●	F		●	●	4	6
CAMEXI	house finch					f	f		F	f		F	f		●	●	2	4
	R	0	0	0	0	0	0	0	2	0	0	1	0	0	3	3		
	F	0	0	0	0	0	0	0	3	1	0	3	2	0	3	3		

Appendix 7. Life form 10: reproduces primarily in conifers; feeds in shrubs, trees, or air. (7 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	BIRDS																R	F
EMDI	western flycatcher				f	F	F		●	●	f	●	●	f	●	●	6	8
GYCY	pinyon jay					f	f	f	●	●	f	●	●	f	●	●	6	6
RECA	ruby-crowned kinglet								f	f	f	●	f	f	●	f	2	2
DECOR	yellow-rumped warbler					f	f		0	f	f	●	f	f	●	f	2	2
DENI	black-throated gray warbler								f	f	f	F	F	f	●	●	2	4
DETO	Townsend's warbler								f	f	f	f	f	f	●	f	1	1
PILU	western tanager								F	F	F	●	F	F	●	F	2	8
	R	0	0	0	0	0	0	0	2	2	0	5	2	0	7	3		
	F	0	0	0	0	1	1	0	3	3	1	6	4	1	7	4		

Appendix 7. Life form 11: reproduces in trees; feeds on ground, in shrubs, trees, or air. (13 species)

Letter code	Species	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgr.	low sagebrush/bunchgrass	black greasewood grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountainmahogany/bunchgr.	curlleaf mountainmahogany/pinegr	juniper sagebrush bunchgr.	curlleaf mountainmahogany shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	Number of plant communities used by each species for:	
	BIRDS																	R	F
ACGE	northern goshawk												F	●		F	●	2	4
ACST	sharp-shinned hawk						f	f		F	f	f	F	f	f	●	●	2	4
ACCO	Cooper's hawk						F	F		F	F	f	●	●	f	●	●	4	8
ZEMA	mourning dove			F	f		0	F		●	R	R	●	R	R	●	R	8	5
ASOT	long-eared owl						f	f		f	f		●	0		●	●	3	3
TYVE	western kingbird						F			●			●		0	●	●	4	5
COSO	western wood pewee						F	f		F	f	f	●	f	f	●	●	3	5

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree shrub				
		bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
																	R	F
CYST	Steller's jay					f	f		F	f	f	●	f	F	●	●	3	5
COBRA	American crow		F	f		F	f		F	f	0	●	0	R	●	R	4	5
VIOL	red-eyed vireo					f			0	f	f	0	f	f	●	f	1	1
VIGI	warbling vireo					f			0	f	f	●	f	0	●	0	2	2
CAPU	purple finch		F			f			f		f	●	f	0	●	0	2	3
SPARB	American tree sparrow		F			F			F	F	0	●	F	0	●	F	2	8
	R	0	0	0	0	0	0	0	2	1	1	10	3	2	13	9		
	F	0	4	0	0	5	2	0	8	2	0	12	3	1	13	8		

Appendix 7. Life form 12: reproduces on very thick branches; feeds on ground or in water. (6 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	BIRDS																R	F
ARHE	great blue heron	f	F	f					R		R	R	R	R	R	R	7	1
CAAL	common egret	f	F	f					R		R	R	R	R	R	R	7	1
BUJA	red-tailed hawk	f	F	F	f	F	F	f	F	F	R	●	●	R	●	●	6	10
AQCH	golden eagle	f	F	F	f	F	F	f	F	F	R	●	●	R	●	●	6	10
PAHA	osprey												R			R	2	0
BUVIR	great horned owl	f	F	F	f	F	F	f	F	F	R	●	●	R	●	●	6	10
	R	0	0	0	0	0	0	0	2	0	5	5	6	5	5	6		
	F	0	5	3	0	3	3	0	3	3	0	3	3	0	3	3		

Appendix 7. Life form 13: reproduces – excavates own hole in a tree; feeds on ground, in shrubs, trees, or air. (9 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	BIRDS																R	F
COAU	common flicker	f	F	f	f	F	f	f	F	f	●	●	●	●	●	●	6	9
MELE	Lewis' woodpecker				f	F	f	f	f	f	●	●	●	●	●	●	6	8
SPVAR	yellow-bellied sapsucker								F	f	0	●	0	●	●	●	4	5
SPTH	Williamson's sapsucker								F	f	0	●	0	●	●	●	4	5
PIVI	hairy woodpecker								f			0	0	0	●	●	2	2
PIPU	downy woodpecker								F	f	0	●	0	0	●	●	3	4
PIAL	white-headed woodpecker								f	f	0	●	0	0	●	●	3	3
SICAR	white-breasted nuthatch								f	f	●	●	●	●	●	●	6	6
SICAN	red-breasted nuthatch								f	f	●	●	●	●	●	●	6	6
	R	0	0	0	0	0	0	0	0	0	4	8	4	6	9	9		
	F	0	1	0	0	2	0	0	5	0	4	8	4	6	9	9		

Appendix 7. Life form 14: reproduces in a hole made by another species or that has occurred naturally; feeds on ground, in water, or air. (25 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
		bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	BIRDS																R	F
AISP	wood duck											R	R		R	R	4	0
BUIS	Barrow's goldeneye											R	R		R	R	4	0
MEMER	common merganser											0			●		1	1
FASP	American kestrel	f	F	f	f	F	f	f	F	f	0	●	●	●	●	●	5	8
TYAL	barn owl	f	F	f	f	f	f	f	F	f	0	●	●	0	●	●	4	6
OTAS	common screech owl	f	F	f	f	f	f	f	F	f	0	●	●	0	●	●	4	6
OTFL	flammulated owl												●			●	2	2
GLGN	pygmy owl	f	F	f	f	f	f	f	F	f	0	●	●	0	●	●	4	6
AEAC	saw-whet owl					f			F			●	0		●	●	3	4
CHVA	Vaux's swift	f	F	f	f	F	F	f	F	F	0	●	●	0	●	●	4	9
MYCI	ash-throated flycatcher					F	F		F	F	●	0	●	●	0	●	4	8
TATH	violet-green swallow	f	F	f	f	F	f	f	F	f	R	0	0	R	0	0	2	3
IRBI	tree swallow	f	F	f	f	F	f	f	F	f	R	0	0	R	0	0	2	3
PAATR	black-capped chickadee								F		0	●	0	0	●	0	2	3
CEFA	brown creeper								f		0	●	0	0	●	0	2	2
TRAE	house wren					f			F		0	●	0	0	●	0	2	3
SIME	western bluebird	f	F	F	f	F	F	f	F	F	●	●	●	●	●	●	6	12
SICU	mountain bluebird	f	F	F	f	F	F	f	F	F	●	●	●	●	●	●	6	12
STVU	European starling	f	F	F	f	F	F	f	F	F	0	●	0	0	●	0	2	8
PADO	house sparrow	f	f	f	f	F	F	f	F	F	0	●	0	0	●	0	2	6
	MAMMALS																	
MYYU	Yuma myotis				f	f	F	f	f	F	●	●	●	●	●	●	6	8
MYEV	long-eared myotis				f	f	F	f	f	F	●	●	●	●	●	●	6	8
MYVO	long-legged myotis						F			F				●	●	●	3	5
LANO	silver-haired bat						F			F	●	●	●	●	●	●	6	8
PRLO	raccoon	f	F	f	f	F	F	f	F	F	f	●	●	f	●	●	4	9
	R	0	0	0	0	0	0	0	0	0	8	19	15	10	21	17		
	F	0	11	3	0	10	11	0	16	11	6	17	13	8	19	15		

Appendix 7. Life form 15: reproduces underground in burrow; feeds on or under ground. (32 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	REPTILES																R	F
SOSE	western ground snake	F	●	●	F	●	●	F	0	0	F	0	0				4	8
	BIRDS																	
ATCU	burrowing owl	f	●	●	f	●	●		0	0		0	0		f	f	4	4
	MAMMALS																	
SOME	Merriam shrew			●			●			●			●			●	5	5
EUMI	least chipmunk					f	0		F	●		f	●		F	●	3	5
EUQM	yellow pine chipmunk											●	●		●	●	4	4
AMLE	antelope ground squirrel					0	●		0	●							2	2
SPTO	Townsend ground squirrel			●		0	●		0	0			●		0	●	4	4
SPRI	Richardson ground squirrel			0		●	●		0	0					0	0	2	2
SPBE	Belding ground squirrel		●	●		●	●		0	0							4	4
SPCO	Columbian ground squirrel		●	●													2	2
SPLA	mantled ground squirrel			0		F	●		f	●		F	●		f	●	4	6
THTO	Townsend pocket gopher		●	●		●	●		0	0		●	●		●	●	8	8
THTA	northern pocket gopher		●	●		●	●		●	●		●	●		●	●	10	10
PELO	little pocket mouse			0		●	●		0	0							2	2
PEPA	Great Basin pocket mouse			0		0	0		●	●		●	●		●	●	6	6
MIME	dark kangaroo mouse			0		●	●		0	0							2	2
DIOR	Ord kangaroo rat		0	0		0	0		●	●		●	●		●	●	6	6
DIMI	chisel-toothed kangaroo rat		0	0		0	0		●	●					0	0	2	2
REME	western harvest mouse			0		0	0		●	●		●	●		●	●	6	6
PEMA	deer mouse	f	0	0	f	0	0		●	●	f	●	●	f	●	●	6	6
ONLE	northern grasshopper mouse	f	f	0	f	0	0		●	●		●	●		●	●	6	6
MIMO	montane vole		0	●		0	0		●	●		0	●		0	●	5	5
MILO	long-tailed vole		0	●		0	●		●	●		0	●		0	●	6	6
LACU	sage vole		F	●		F	●		●	●		f	●		F	●	6	9
ZAPR	western jumping mouse		0	●		0	●		0	●		0	●		0	●	5	5
CALAT	coyote	f	F	F	f	f	●		f	●	f	●	●	f	●	●	6	8
VUVU	red fox					F									●	●	2	3
VUMA	kit fox					F	●		F	●							2	4
MUER	short-tailed weasel											F	0		●	●	2	3
MUFR	long-tailed weasel		F	0		0	0		●	●		●	●		●	●	6	7
TATA	badger		f	f		0	0		●	●		●	●		●	●	6	6
MEMEP	striped skunk		f			0	f		●	F		F	F		●	●	3	6
	R	0	6	12	0	8	17	0	13	19	0	11	19	0	14	22		
	F	1	9	13	1	12	17	1	15	20	1	14	20	0	16	22		

Appendix 7. Life form 16: reproduces underground in burrow; feeds in water, on ground, or in air. (9 species)

		Structural conditions																
		Grass-forb			Low shrub			Tall shrub			Tree			Tree/shrub				
Letter code	Species	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass	bare ground	annuals	bunchgrass		
	BIRDS																R	F
MEAL	belted kingfisher					R	R		R	R					R	R	6	0
RIRI	bank swallow		F			●	●		●	●		●	●		●	●	8	9
STRU	rough-winged swallow		F			●	●		●	●		●	●		●	●	8	9
	MAMMALS																	
SOPR	Malheur shrew		0	●		0	●		0	●		0	●		0	●	5	5
SOVA	wandering shrew		0	●		0	●		0	●		0	●		0	●	5	5
CACAN	beaver					f	0		f	0		●	●		●	●	4	4
ONZI	muskrat					0	0		●	●		F			●	●	4	4
MUVI	mink		F			0	0		●	●		F			●	●	4	4
LUCA	river otter		F			0	0		●	●		F			●	●	4	4
	R	0	0	2	0	3	5	0	5	8	0	3	5	0	7	9		
	F	0	4	2	0	2	4	0	5	7	0	6	5	0	6	8		

Appendix 8. Composite occurrence and orientation list for 341 wildlife species in southeastern Oregon.

Reproduction orientations

▧, ● Primary (≥40%)

▨, Secondary (<40%)

Feeding orientations

■, ■ Primary (≥40%)

□, □ Secondary (<40%)

L – Low

M – Medium

H – High

				Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December		
		AMPHIBIANS															
AMMA	2	long-toed salamander	L	□	■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	■	■	■	□	approx. 50 eggs/♀	h.r. ≤30.5 m (100 ft)/adult
SCIN	2	Great Basin spadefoot	L	□	□	■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	■	■	□	□	≥100/♀	strong homing response; density 300-900/ac
BUBO	2	western toad	L	□	□	■	▧ ■	▧ ■	▧ ■	▨ ■	▨ ■	■	■	□	□	100+ eggs/♀	h.r. approx. 16.2 m^2 (174.3 ft^2)/ adult
ODHE	5	mule deer	M	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	1-2 fawns	
ANAMER	5	pronghorn	L	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	1-3; avg. 2 kids	
OVCA	5	bighorn sheep	L	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	1-2; avg. 1 lamb	
FECO	4	cougar	M	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	1-5; avg. 3; 1 litter	6,475 ha (16,000 ac)
FECA	5	feral house cat	L	■	■	▧ ■	▧ ■	▧ ■	▧ ■	■	■	■	■	■	■	4-6; 1+ litters	
LYRU	4	bobcat	M	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	1-6; avg. 3-4; 1 litter	518 ha (1,280 ac)
EQCA	5	feral horse	L	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	▧ ■	1-2; avg. 1 foal	

NOTE: See footnotes at end of appendix 8, p. 138.

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush bunchgrass	low sagebrush/bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountain mahogany bunchgr.	curlleaf mountainmahognay pinegr	juniper sagebrush bunchgrass	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
one 0.8-ha (2-ac) pond/ population			● ■			○ □										● ■	● ■	● ■	● ■	● ■		● ■	0
≥2.0 ha (5 ac)/population	● ■		■	■			□	● ■	□	■	■	□	□	■	□	● ■	● ■	● ■	● ■	● ■		● ■	-
≥25.0 ha (62 ac)/population	□	■	■	■	□	○	□	● ■	■	□	□	□	□	■	■	● ■	● ■	● ■	● ■	● ■		● ■	0
	□	■	■	■	■	■	■	● ■	■	● ■	● ■	● ■	● ■	□	■	■	■	■	■	□	□	□	-
	● ■				■	● ■	■	● ■	■	■	■	■	■			■	□	■		■	□		-
	□	■	■	■	■	■	□	■	□	● ■	● ■	□	● ■	□	□	■	■	■	□	□	■	□	-
		■						● ■		● ■	● ■	● ■	● ■	■	■	■	■	□		□	■	□	-
							● ■					● ■		■	■	● ■	● ■	● ■	□	□	□		+
		■	■	■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	○ □	□	□	□	-
			● ■	● ■	○ □	○ □	■	● ■	○ □	○ □	○ □	● ■	○ □	○ □	○ □	○ □	○ □	○ □	○ □	○ □	□		+

Reproduction orientations

▨, ● Primary (>40%)

▧, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

█, Secondary (<40%)

L – Low

M Medium

H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				January	February	March	April	May	June	July	August	September	October	November	December		
CECAN	5	elk	L	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	1-2 calves	
MUVI	16	mink	L	░	░	░	▨ ░	▨ ░	░	░	░	░	░	░	░	2-10; avg. 4; 1 litter	1.6 stream km (1 stream mi)
TATA	15	badger	L	░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░	░	2-5; 1 litter	
SPPU	4	spotted skunk	M	░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░	░	1.5; 1 litter	≥259 ha (640 ac)
MEMEP	15	striped skunk	L	░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░	░	2-10; avg. 6-7; 1 litter	17-38 ha (43-95 ac)
LUCA	16	river otter	L	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	1-5; avg. 2-3; 1 litter	80 stream km (50 stream mi)
VUVU	15	red fox	L	░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░	░	2-10; avg. 5-6; 1 litter	259-777 ha (640-1,920 ac)
VUMA	15	kit fox	L														
PRLO	14	raccoon	L	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	1-7; avg. 2-3; 1 litter	449 ha (1,110 ac)
MUER	15	short-tailed weasel	L	░	░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	░	4-13; avg. 6-7; 1 litter	
MUFR	15	long-tailed weasel	M	░	░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░	░	4-9; avg. 6-8; 1 litter	approx. 259 ha (640 ac)

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm wet meadows	seasonally wet meadows	shadscale saltbush bunchgrass	low sagebrush bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountain mahogany bunchgr	curlleaf mountainmahognay pinegr.	juniper sagebrush bunchgrass	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats¹
										■	■	■	■	● ■	● ■	● ■	● ■	○			● ■		-
1.6 stream km (1 stream mi)/ pair								□								● ■	● ■	● ■	● ■	● ■	● ■		0
	□	□	□	□	□	● ■	□	● ■	□	□		● ■	□	□		● ■	○ □	● ■		● ■	□		+
≥259 ha (640 ac)/pair								● ■				● ■				● ■	● ■		□	● ■			0
≥259 ha (640 ac)/pair								● ■								● ■	● ■			● ■			0
≥80 stream km (50 stream mi)/ pair																● ■	● ■	● ■	□	● ■	● ■	□	0
518-777 ha (1,280-1,920 ac)/ pair																● ■	● ■		■	● ■			+
					● ■	● ■	● ■															● ■	+
3.2 stream km (2 stream mi)/ pair								□				□				● ■	● ■	● ■	□		□		0
		○ □														● ■	● ■				● ■		0
259 ha (640ac)/pair	● ■	● ■	● ■	● ■	○ □	○ □	□	● ■	○ □	● ■	● ■	● ■	● ■	○ □	○ □	● ■	● ■	● ■	● ■	● ■	● ■	□	0

Reproduction orientations

▧ ● Primary (>40%)

▨ Secondary (<40%)

Feeding orientations

░ ■ Primary (>40%)

▓ Secondary (<40%)

L – Low

M – Medium

H – High

				Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December		
RARA	5	black rat	L														
RANO	5	Norway rat	L		▧	▧	▧	▧	▧	▧	▧	▧	▧	▧		6-22; avg. 6-8; 8 litters	
				░	░	░	░	░	░	░	░	░	░	░	░		
ZAPR	15	western jumping mouse	L					▧	▧	▧	▧	▧				2-7; 1 litter	
				░	░	░	░	░	░	░	░	░	░	░	░		
ERDO	4	porcupine	L						▧	▧	▧	▧	▧			1 young	101-146 ha (250-360 ac)
				░	░	░	░	░	░	░	░	░	░	░	░		
CALAT	15	coyote	M			▧	▧	▧								4-19; avg. 5-7; 1 litter	
				░	░	░	░	░	░	░	░	░	░	░	░		
NECI	4	bushy-tailed woodrat	M		▧	▧	▧	▧	▧	▧						1-6; avg. 2-4; 1 litter	
				░	░	░	░	░	░	░	░	░	░	░	░		
MIMO	15	montane vole	L	▧	▧	▧	▧	▧	▧	▧	▧	▧	▧	▧	▧	2-8; avg. 5-6; 4 + litters	
				░	░	░	░	░	░	░	░	░	░	░	░		
MILO	15	long-tailed vole	L			▧	▧	▧	▧	▧	▧	▧	▧	▧		2-10; avg. 3-6	
				░	░	░	░	░	░	░	░	░	░	░	░		
LACU	15	sage vole	L	▧	▧	▧	▧	▧	▨	▨	▨	▨	▧	▧	▧	2-13; avg. 4-6; 4 + litters	
				░	░	░	░	░	░	░	░	░	░	░	░		
ONZI	16	muskrat	L				▧	▧	▧	▧	▧	▨	▨			2-16; avg. 6-8; 2 litters	
				░	░	░	░	░	░	░	░	░	░	░	░		
REME	15	western harvest mouse	M			▧	▧	▧	▧	▧	▧	▧	▧			1-9; avg. 2-4; 1 + litters	
				░	░	░	░	░	░	░	░	░	░	░	░		
PECR	4	canyon mouse	M				▧	▧	▧	▧						3-5; 1 + litters	
				░	░	░	░	░	░	░	░	░	░	░	░		

Minimum habitat required pair or population ac – acres ha - hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm wet meadows	seasonally wet meadows	shadscale saltbush bunchgrass	low sagebrush bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountain mahogany bunchgr	curlleaf mountainmahognay pinegr	juniper sagebrush bunchgrass	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and or edaphic	Manmade habitats[1]
								● ■						● ■	● ■	● ■	● ■			● ■			+
								● ■						● ■	● ■	● ■	● ■			● ■			+
16 ha (40 ac)/population		● ■	● ■													● ■	● ■	● ■	● ■	● ■	● ■		-
2,590 ha (6,400 ac)/ population								● ■		● ■	● ■	● ■	● ■		□	● ■	● ■	■	■	□	□		-
	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■			● ■	● ■	● ■	□	□	□	○ □	-
32 ha (80 ac) population					■	■	■	● ■	■	■	■	● ■	■									● ■	+
8 ha (20 ac)/population		● ■	● ■	□			□	● ■				□		□		● ■	● ■	● ■	● ■	● ■	● ■		0
16 ha (40 ac)/population		● ■	● ■	● ■			○ □	● ■				● ■				● ■	● ■	● ■	● ■	● ■	● ■		0
16 ha (40 ac)/population	● ■	● ■				● ■		● ■				● ■										○	0
1.6 stream km (1 stream mi)/ population																● ■	● ■	● ■	● ■	● ■			0
16 ha (40 ac)/population							● ■	● ■	● ■	□		● ■	□			● ■	● ■	● ■	● ■	● ■	● ■		+
0.8 km (0.5 mi) cliff/ population								● ■				● ■				● ■	● ■					● ■	0

Reproduction orientations
▨, ● Primary (>40%)
▨, ○ Secondary (<40%)

Feeding orientations
▩, ■ Primary (>40%)
■, □ Secondary (<40%)

L – Low
M – Medium
H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				January	February	March	April	May	June	July	August	September	October	November	December		
PEMA	15	deer mouse	M	■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	■	■	■	1-9; avg. 3-5; ± 6 litters	greasewood ♂ 372 m^2, ♀ 299 m^2; big sage ♂ 372 m^2, ♀ 392 m^2
ONLE	15	northern grasshopper mouse	L	■	● ■	● ■	● ■	● ■	● ■	● ■	■	■	■	■	■	4-6; 1 + litters	
NELE	4	desert woodrat	M														
PEPA	15	Great Basin pocket mouse	L	■	■	■	● ■	● ■	● ■	● ■	■	■	■	■	■	3-8; avg. 5-6; 1-2 litters	greasewood ♂ 288 m^2, ♀ 278 m^2; big sage ♂ 337 m^2, ♀ 267 m^2
MIME	15	dark kangaroo mouse	L														
DIOR	15	Ord kangaroo rat	L	■	● ■	● ■	● ■	● ■	● ■	● ■	■	■	■	■	■	1-6; avg. 4; 1-2 litters	
DIMI	15	chisel-toothed kangaroo rat	L														
CACAN	16	beaver	L	■	■	■	■	● ■	● ■	● ■	■	■	■	■	■	1-9; avg. 2-4; 1 litter	
SPCO	15	Columbian ground squirrel	L	□	□	● ■	● ■	● ■	○ ■	○ ■	■	■	□	□	□	2-7; avg. 3-4; 1-2 litters	
SPLA	15	mantled ground squirrel	L	□	□	■	● ■	● ■	● ■	● ■	● ■	■	□	□	□	4-8; avg. 5-6; 1-2 litters	
THTO	15	Townsend pocket gopher	M	■	● ■	● ■	● ■	● ■	■	■	■	■	■	■	■	3-8; 1-2 litters	

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
≥16 ha (40 ac)/population	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■		·
32 ha (80 ac)/population					□ □	□ □		■ ■				■ ■											-
					● ■	● ■	● ■	● ■															+
16 ha (40 ac)/population	□				● ■	● ■	● ■	● ■	□	□	□	● ■	□									○	0
					● ■																	● ■	0
32 ha (80 ac)/population					● ■		● ■	● ■														□	0
					● ■		● ■	□															0
1.6 stream km (1 stream mi)/ colony																● ■	● ■	● ■		● ■			-
32 ha (80 ac)/population			● ■																				0
16 ha (40 ac)/population						● ■		● ■		● ■	● ■	● ■	● ■									● ■	+
16 ha (40 ac)/population	● ■		● ■	● ■	● ■	● ■	● ■	● ■								● ■		● ■		● ■			+

Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

█, □ Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
THTA	15	northern pocket gopher	M	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	4-7; 1-2 litters	
PELO	15	little pocket mouse	L														density 3-29/ha, avg. 14-15
MAFL	4	yellow-bellied marmot	M	█	█	▧ ░	▧ ░	░	░	░	░	░	░	█	█	4-8; avg. 4-6; 1 litter	
AMLE	15	antelope ground squirrel	L														density 1-4/ha
SPTO	15	Townsend ground squirrel	L	█	▧ ░	▧ ░	▧ ░	░	░	█	█	█	█	█	█	5-10; avg. 8-10; 1-2 litters	
SPRI	15	Richardson ground squirrel	L														
SPBE	15	Belding ground squirrel	L	█	█	▧ ░	▧ ░	▧ ░	▧ ░	░	█	█	█	█	█	6-7; 1 litter	
SYNU	5	mountain cottontail	L	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	4-8; avg. 6; 1-2 litters	
LETO	5	white-tailed jackrabbit	L	░	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	3-6; 2-3 litters	
LECA	5	black-tailed jackrabbit	M	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	1-6; avg. 2; 3-4 litters	
EUMI	15	least chipmunk	L	█	█	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	█	4-6; 1-2 litters	greasewood ♂ 453 m^2, ♀ 419 m^2; big sage ♂ 413 m^2, ♀ 433 m^2

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
16 ha (40 ac)/population	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	■	● ■	● ■	● ■	□	● ■	● ■		+
					● ■																		0
		● ■	● ■	○ □		● ■		● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■				● ■	+
					● ■		● ■															● ■	0
32 ha (80 ac)/population	● ■			● ■				● ■								● ■		● ■		● ■		○ □	0
								● ■														○ □	0
16 ha (40 ac)/population		● ■	● ■	○ □		● ■		● ■								● ■	● ■	● ■		● ■		○ □	0
≥41 ha (100 ac)/population					○ □	● ■	● ■	● ■	○ □	● ■	● ■	● ■	● ■			● ■	● ■			● ■		● ■	0
≥65 ha (160 ac)/population	■	■	■	□				● ■	■	■	■	■	■			■	■			■		● ■	-
≥65 ha (160 ac)/population	■	■	■	■	■	● ■	■	● ■	■	■	■	■	■			■	■			■		● ■	-
≥32 ha (80 ac)/population					○ □	● ■	● ■	● ■		● ■	● ■	○ □	● ■									○ □	0

Reproduction orientations
▨, ● Primary (>40%)
▧, ○ Secondary (<40%)

Feeding orientations
░, ■ Primary (>40%)
■, □ Secondary (<40%)

L – Low
M – Medium
H – High

				Activity/seasonal occurrence													
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
EUAM	15	yellow pine chipmunk	L	■	■	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	■	5-7; 1 litter	
LACI	9	hoary bat[2]					░	░	░	░	░	░	░			2 young	
EUMAC	4	spotted bat	L	■	■	░	░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	■	■	1 young	
PLTO	4	western big-eared bat	M	■	■	░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	■	■	1 young	
ANPA	4	pallid bat	M	■	■	░	░	░	▨ ░	▨ ░	▨ ░	░	░	■	■	2 young	
SYID	5	pygmy rabbit	L	░	░	░	░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░	░	avg. 6; 1-2 litters	
MYCA	4	California myotis	M	■	■	░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	■	■	1 young	
MYLE	4	small-footed myotis	L	■	■	░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	■	■	1 young	
LANO	14	silver-haired bat[2]	L	■	■	░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	■	■	2 young	
PIHE	4	western pipistrelle	L	■	■	░	░	░	░	▨ ░	▨ ░	▨ ░	░	■	■	2 young	
EPFU	4	big brown bat	M	■	■	░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	░	■	■	1 young	

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
≥32 ha (80 ac)/population								● ■				● ■										○	+
																							0
					● ■			□								● ■	● ■	● ■		● ■		● □	0
								● ■								● ■	● ■	● ■	□	● ■	□	● □	0
			□	□	□	□	□	● ■	□			● ■		□	□	● ■	● ■	● ■	□	● ■	□	● □	0
≥243 ha (600 ac)/population					● ■	● ■	● ■	● ■				● ■										● ■	0
			□	□			□	● ■				● ■		□	□	● ■	● ■	□	● ■	□		● □	0
								● ■								● ■	● ■	□	● ■	□		● □	0
					■	■	■	■	■	■	■	■	■			● ■	● ■	○ □	● ■	○ □		□	0
								● ■				□				● ■	● ■	□	● ■	□		● □	0
		□	□	□			□	● ■		□	□	● ■	□	○ □	○ □	● ■	● ■	○ □	● ■	□		● □	0

Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

■, □ Secondary (<40%)

L – Low

M – Medium

H – High

				Activity/seasonal occurrence													
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
MYLU	4	little brown myotis	M	■	■	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	■	■	1 young	
MYYU	14	Yuma myotis	L	■	■	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	■	■	1 young	
MYEV	14	long-eared myotis	L	■	■	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	■	■	1 young	
MYTH	4	fringed myotis	L														
MYVO	14	long-legged myotis	L	■	■	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	■	■	1 young	
PLNI	5	snow bunting[2]		░	░	░									░	4-6	
		MAMMALS															
SOPR	16	Malheur shrew	L	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░		
SOVA	16	wandering shrew	L	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	2-9; avg. 4-6; 1 litter	372 m^2 (4,000 ft^2)
SOME	15	Merriam shrew	L	░	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	5-7; 1 litter	
ZOAT	7	golden-crowned sparrow[2]		░	░	░								░	░	4-5	

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
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																						□	0

≥2 ha (5 ac)/population		● ■	● ■													● ■	● ■	○ □	● ■	○ □	○ □		0
≥2 ha (5 ac)/population		● ■	● ■					● ■								● ■	● ■	○ □	● ■	○ □	○ □		0
≥8.1 ha (20 ac)/population						● ■		● ■				● ■											0
																						□	0

Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

█, □ Secondary (<40%)

L – Low

M – Medium

H – High

				Activity/seasonal occurrence													
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
PAIL	7	fox sparrow[2]					░	▧ ░	▧ ░	▧ ░	░	░				4-5	
MELI	6	Lincoln's sparrow[2]				░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░		4-5	
MEMEL	7	song sparrow	L	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	3-5	sage 20.5 ha/pr.; aspen 2.2 ha/pr.
CALA	5	Lapland longspur[2]		░	░	░									░	4-7	
JUHY	5	northern junco	M	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	4-5	juniper 2.4-13.5 ha/pr. (nesting)
SPARB	11	American tree sparrow[2]	L	░	░	░							░	░	░	4-5	
SPPA	7	chipping sparrow	M			░	░	▧ ░	▧ ░	▧ ░	░	░				3-5	juniper 1.4-2.3 ha/pr. (nesting); p. pine 1.9-2.5 ha/pr. (nesting)
SPBRE	7	Brewer's sparrow	L				▧ ░	▧ ░	▧ ░	▧ ░	░	░				3-4	sage 1.1-1.5 ha/pr.
ZOLE	7	white-crowned sparrow[2]		░	░	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	3-5	
AMSA	5	grasshopper sparrow	L				▧ ░	▧ ░	▧ ░	░	░					4-5	
POGRA	5	vesper sparrow	L			░	▧ ░	▧ ░	▧ ░	░	░	░				4-6	

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats¹
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																						□	0
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density – 25/100 ha						● ■	□	● ■	□	□	□	● ■	■	□	● ■	□	□	□	□	□	□	□	0
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Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

█, □ Secondary (<40%)

L – Low

M – Medium

H – High

				Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December		
CHGR	5	lark sparrow	M			░	▧ ░	▧ ░	▧ ░	░	░	░				3-5	
AMBI	7	black-throated sparrow				░	▧ ░	▧ ░	▧ ░	░	░	░					aspen 4.2 ha/pr.
AMBE	7	sage sparrow	L			▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░			3-4	sage 1.2-1.7 ha/pr. (nesting)
CATR	8	American goldfinch	M				░	░	▧ ░	▧ ░	░	░	░			3-6	aspen 3.9 ha/pr.
CAPS	7	lesser goldfinch	L				░	░	▧ ░	▧ ░	░	░	░			4-5	
PICH	7	green-tailed towhee	M				▧ ░	▧ ░	▧ ░	░	░	░				4	aspen 3.7 ha/pr.
PIER	7	rufous-sided towhee	M		░	░	▧ ░	▧ ░	▧ ░	░	░	░	░			3-6	aspen 7.5 ha (18.6 ac)/pr.
PASA	5	savannah sparrow	L				▧ ░	▧ ░	▧ ░	░	░					4-5	
CACAS	11	Cassin's finch[2]		░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	4-5	juniper 6.7 ha/pr. (nesting); aspen 3.9 ha (9.8 ac)/pr.
CAMEXI	9	house finch	L	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	4-5	juniper 1.5-1.9 ha/pr. (nesting)
LEAT	4	black rosy finch[2]	L	░	░	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	3-5	

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
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density – 50/100 ha (good)						●		●				●	●		●								0
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Reproduction orientations

▨, ● Primary (>40%)

▧, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

▓, □ Secondary (<40%)

L – Low

M – Medium

H – High

				Activity/seasonal occurrence													
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
CAFL	9	common redpoll[2]		░	░										░		
CAPI	11	pine siskin[2]		░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	░	3-6	aspen 2.5 ha/pr.
PHME	11	black-headed grosbeak[2]			░	░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░			3-4	aspen 5.8 ha/pr.
PACY	8	indigo bunting[2]						▨ ░	▨ ░	▨ ░	░	░					
PAAMO	7	lazuli bunting	L					▨ ░	▨ ░	░	░	░				3-4	
HEVE	11	evening grosbeak[2]		░	░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	3-4	
CAPU	11	purple finch	L	░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	░	4-5	aspen 3.4 ha (9.3 ac)/pr.
ICGA	9	northern oriole	L				▨ ░	▨ ░	▨ ░	▨ ░	░					3-6	ranges from 2.7 ha to colonial with 17 prs./ha
EUCY	7	Brewer's blackbird	M	░	░	░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	4-6	
MOAT	7	brown-headed cowbird	M		░	░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░			4-6	
PILU	10	western tanager	L				▨ ░	▨ ░	▨ ░	▨ ░	░	░				3-5	p. pine 10.1 ha/pr. (nesting)

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountain mahogany bunchgr.	curlleaf mountainmahognay pinegr.	juniper sagebrush bunchgrass	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and or edaphic	Manmade habitats[1]
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Reproduction orientations
▧, ● Primary (>40%)
▨, ○ Secondary (<40%)
Feeding orientations L – Low
░, ■ Primary (>40%) M – Medium
▓, Secondary (<40%) H – High

				Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December		
PHLU	9	rose-breasted grosbeak[2]															aspen 3.6 ha (8.9 ac)/pr.
PADO	14	house sparrow	L	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	5-6/clutch; 1-3 clutches	
DOOR	5	bobolink	L					▧ ░	▧ ░	▧ ░	░	░				4-7	
STNEG	5	western meadowlark	M	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	3-7	sage 20.5 ha/pr. (nesting)
XAXA	3	yellow-headed blackbird	L				▧ ░	▧ ░	░	░	░	░	░	░		3-5	
AGPH	7	red-winged blackbird	M	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	3-5	
GETR	3	common yellowthroat	L				▧ ░	▧ ░	▧ ░	░	░	░				3-5	
ICVI	8	yellow-breasted chat	L				▧ ░	▧ ░	▧ ░	░	░	░				3-5	
SEAU	7	ovenbird[2]															
WIPU	5	Wilson's warbler	L				▧ ░	▧ ░	▧ ░	░	░	░				3-6	
SERUT	9	American redstart[2]					▧ ░	▧ ░	▧ ░	░	░	░				3-5	aspen 3.3 ha/pr.

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
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0.4-2.0 ha (1-5 ac)alkali marsh/population			□	□				□								● ■	□	□	● ■	○ □		□	0
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														□	□	● ■	● ■	● ■		□	□	□	0

Reproduction orientations

▧ , ● Primary (>40%)

▨ , Secondary (<40%)

Feeding orientations

░ , ■ Primary (>40%)

▓ , Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				Activity/seasonal occurrence													
DEPE	8	yellow warbler	L				░	▧ ░	▧ ░	░	░	░				4-5	aspen 1.8 ha (4.4 ac)/pr.
DECOR	10	yellow-rumped warbler	L			░	▧ ░	▧ ░	▧ ░	░	░	░	░			3-5	p. pine 1.4-1.9 ha/pr. (nesting); aspen 2.6 ha (6.4 ac)/pr.
DENI	10	black-throated gray warbler	L				▧ ░	▧ ░	▧ ░	░	░	░				3-5	juniper 20.5 ha/pr. (nesting)
DETO	10	Townsend's warbler	L				▧ ░	▧ ░	▧ ░	░	░	░				3-5	
OPTO	7	MacGillivray's warbler					▧ ░	▧ ░	▧ ░	░	░	░				3-5	aspen 3.7 ha/pr.
STVU	14	European starling	L	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	4-6/clutch; 1-6 clutches	
VISO	11	solitary vireo[2]					▧ ░	▧ ░	▧ ░	▧ ░	░	░				3-5	
VIOL	11	red-eyed vireo	L					▧ ░	▧ ░	▧ ░	░	░				3-4	aspen 1.4 ha (3.4 ac)/pr.
VIGI	11	warbling vireo	L				▧ ░	▧ ░	▧ ░	▧ ░	░	░				3-5	aspen 1.6 ha (3.9 ac)/pr.
VECE	6	orange-crowned warbler	L				░	▧ ░	▧ ░	░	░	░				4-6	
ANSP	5	water pipit[2]				░	░	░	▧ ░	▧ ░	▧ ░	░	░			4-7	

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
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Reproduction orientations

▨, ● Primary (>40%)

▧, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

▓, □ Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
BOGA	9	Bohemian waxwing[2]		■	■									■	■	4-6	
BOCE	9	cedar waxwing	L	■	■	■	■	■	● ■	● ■	■	■	■	■	■	3-6	
LAEX	7	northern shrike[2]		■	■	■	■						■	■	■	4-6	
LALU	7	loggerhead shrike	M			■	● ■	● ■	● ■	■	■	■				4-7	
SICU	14	mountain bluebird	M				● ■	● ■	● ■	● ■	■	■	■			4-6	juniper 1.8-2.3 ha/pr.
MYTO	6	Townsend's solitaire	M	■	■	■	● ■	● ■	● ■	● ■	■	■	■	■	■	3-5	juniper 8.1 ha/pr.
POCAE	7	blue-gray gnatcatcher	M														
RESA	10	golden-crowned kinglet[2]		■	■	■	● ■	● ■	● ■	■	■	■	■	■	■	5-9	
RECA	10	ruby-crowned kinglet	L				● ■	● ■	● ■	■	■	■				6-9	
IXNA	11	varied thrush[2]		■	■	■				■	■	■	■	■	■	3-5	
CAGN	5	hermit thrush[2]					● ■	● ■	● ■	■	■					3-5	p. pine 10-13.5 ha/pr.; aspen 3.4 ha/pr.

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
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																						□	+
					■	■	● ■	● ■	■	■	■	● ■	● ■	■	■	● ■	● ■	● ■	□	○ □	○ □	□	+
aspen 3.4 ha/pr to colonial	□	□	■	■	■	■	■	■	■	■	■	● ■	■	● ■	● ■	● ■	● ■	● ■	□	○ □	○ □	○ □	+
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																						□	0
																						○ □	0

Reproduction orientations

▧, ● Primary (>40%)

▨, Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

█, □ Secondary (<40%)

L – Low

M – Medium

H – High

				Activity/seasonal occurrence													
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
CAUS	7	Swainson's thrush	L				░	▧ ░	▧ ░	▧ ░	░	░				3-5	
CAFU	5	veery	L				▧ ░	▧ ░	▧ ░	░	░	░	░			3-5	aspen 2.2 ha/pr.
SIME	14	western bluebird	M				▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░		4-6	
MIPO	7	northern mockingbird[2]									░	░	░	░		3-6	
DUCA	7	gray catbird	L				▧ ░	▧ ░	▧ ░	░	░	░				3-5	aspen 7.5 ha (18.6 ac)/pr.
TORU	7	brown thrasher	M														
ORMO	7	sage thrasher	L				░	▧ ░	▧ ░	▧ ░	░	░				4-5	sage 2.9-4.5 ha/pr.
TUMI	7	American robin	M	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	3-5	juniper 1.9-3.4 ha-pr.; aspen 2.3 ha (5.6 ac)/pr.
TRAE	14	house wren	L				░	▧ ░	▧ ░	▧ ░	░	░	░			5-8	aspen 1.9 ha/pr.
TRTR	3	winter wren[2]		░	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	5-7	
CIPA	3	marsh wren	L			░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░			3-7	

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
						□	□	● ■	□	■	■	■	■	● ■	● ■	● ■	● ■	● ■					0
			□	□						□	□			□	□	● ■	● ■	● ■		□	□		0
aspen 3.4 ha/pr to colonial	□	□	■	■	■	■	■	■	■	■	■	● ■	■	● ■	● ■	● ■	● ■	● ■	□	□	□		+
																							0
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			□	□												● ■	□	□	● ■	○ ■	○ ■	○ □	0

Reproduction orientations

▧ ● Primary (>40%)

▨ Secondary (<40%)

Feeding orientations

░ ■ Primary (>40%)

▓ Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				January	February	March	April	May	June	July	August	September	October	November	December		
CAMEXO	4	canyon wren	M		░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░		4-6	
SAOB	4	rock wren	M		░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░		5-8	sage 40.5 ha/pr.
PSMI	8	bushtit	M	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	5-7	
SICAR	13	white-breasted nuthatch	L	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	5-9	p. pine 2.5-13.5 ha/pr.
SICAN	13	red-breasted nuthatch	L	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	4-7	p. pine 1.4-2.1 ha/pr.; aspen 7.5 ha-pr.
CEFA	14	brown creeper	L	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	4-8	p. pine 2.5-4.5 ha/pr.
CIME	3	dipper	L	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	3-6	
COBRA	11	American crow	M	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	4-6	
GYCY	10	pinyon jay	L	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	3-4	density 20.3 ha/pr. (nesting)
NUCO	10	Clark's nutcracker[2]		░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	2-4	density 20.3 ha/pr. (nesting)
PAATR	14	black-capped chickadee	L	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	4-9	aspen 5.4 ha/pr.

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm wet meadows	seasonally wet meadows	shadscale saltbush bunchgrass	low sagebrush bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountain mahogany bunchgr.	curlleaf mountainmahognay pinegr	juniper sagebrush bunchgrass	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and or edaphic	Manmade habitats[1]
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Reproduction orientations
▧, ● Primary (>40%)
▨, ○ Secondary (<40%)

Feeding orientations
░, ■ Primary (>40%)
▓, Secondary (<40%)

L – Low
M – Medium
H – High

Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
PAGA	14	mountain chickadee[2]		░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	7-9	juniper 1.8-3.1 ha/pr.; p. pine 1.0-1.9 ha/pr.
PECA	11	gray jay[2]		░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	░	3-5	
CYST	11	Steller's jay	L	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	3-5	
APCO	7	scrub jay	M														
PIPI	7	black-billed magpie	M	░	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	6-9	
COCOR	4	northern raven	H	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	4-7	density ≤25 km²/pr.
IRBI	14	tree swallow	L			░	▧ ░	▧ ░	▧ ░	░	░	░				4-6	aspen 2.3 ha/pr. to colonial
RIRI	16	bank swallow	L				▧ ░	▧ ░	▧ ░	░	░	░				4-5	
STRU	16	rough-winged swallow	L				▧ ░	▧ ░	▧ ░	░	░					4-8	
HIRU	4	barn swallow	M				▧ ░	▧ ░	▧ ░	▧ ░	░	░				4-6	
PEPY	4	cliff swallow	M				▧ ░	▧ ░	▧ ░	▧ ░	░	░				4-6	

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
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≥25 km^2/pair (≥6,400 ac)	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	■	○ ☐	○ ☐	● ■	+
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Reproduction orientations
▧, ● Primary (>40%)
▨, ○ Secondary (<40%)

Feeding orientations
░, ■ Primary (>40%)
▓, □ Secondary (<40%)

L – Low
M – Medium
H – High

				Activity/seasonal occurrence													
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
COSO	11	western wood pewee	L					▧ ░	▧ ░	▧ ░	░	░				3-4	≃ 20.3 ha/pr. – juniper; ≃ 2.5 ha (6.3 ac)/pr. – aspen
NUBO	10	olive-sided flycatcher[2]						▧ ░	▧ ░	▧ ░	░	░				3	
ERAL	5	horned lark	L			░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	3-5	density: 2-5 prs./100 ha – openings; 10-40 prs./100 ha – sage
TATH	14	violet-green swallow	L			░	░	▧ ░	▧ ░	▧ ░	░	░	░			4-5	
SASA	4	Say's phoebe	M		░	░	▧ ░	▧ ░	▧ ░	░	░	░	░			4-5	
EMTR	7	willow flycatcher	M					▧ ░	▧ ░	▧ ░	░	░				3-4	
EMHA	11	Hammond's flycatcher[2]						░	▧ ░	▧ ░	░	░				3-4	
EMWR	7	gray flycatcher	M					▧ ░	▧ ░	▧ ░	░	░				3-4	
EMDI	10	western flycatcher	M					▧ ░	▧ ░	░	░	░				3-4	
PIPU	13	downy woodpecker	L	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	4-7	juniper, p. pine 4.0 ha/pr., aspen 7.5
PIAL	13	white-headed woodpecker	L	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	3-5	nesting terr. 8.1 ha (20.0 ac)/pr.

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
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breeding density: ≃0.8 ha/pr –juniper; 1.3 ha/pr – p. pine; 2.5 ha/pr – aspen					■	■	■	■	■	■	■	■	■	● ■	● ■	● ■	● ■	● ■	■	○ □	○ □	□	0
breeding density: ≃0.8 ha/pr –juniper; 1.3 ha/pr – p. pine; 2.5 ha/pr – aspen												● ■										□	0
breeding density: ≃0.8 ha/pr –juniper; 1.3 ha/pr – p. pine; 2.5 ha/pr – aspen					■	■	■	● ■	■	● ■	● ■	● ■	● ■	● ■	● ■	■	■	■		□	□	□	0
breeding density: ≃0.8 ha/pr –juniper; 1.3 ha/pr – p. pine; 2.5 ha/pr – aspen						□	□	■	■	■	■	● ■	● ■	■	● ■	● ■	● ■	● ■	□	○ □	○ □	□	0
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														■	■	● ■	● ■	● ■		○ □	○ □		0

Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations L – Low

░, ■ Primary (>40%) M – Medium

█, □ Secondary (<40%) H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				January	February	March	April	May	June	July	August	September	October	November	December		
TYTY	7	eastern kingbird	L					▧ ░	▧ ░	▧ ░	░	░	░			3-5	aspen 3.8 ha (9.3 ac)/pr.
TYVE	11	western kingbird	L				░	▧ ░	▧ ░	▧ ░	░	░	░			3-5	
MYCI	14	ash-throated flycatcher	M					▧ ░	▧ ░	▧ ░	░	░	░			3-5	
COAU	13	common flicker	M	░	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	5-10	juniper 4.5 ha/pr.; p. pine 16.2 ha/pr.; aspen 5.0 ha/pr.
PILE	13	Lewis' woodpecker	L			░	░	▧ ░	▧ ░	▧ ░	░	░	░			6-8	nesting terr. 6.1 ha (15.0 ac)/pr.
SPVAR	13	yellow-bellied sapsucker	L				▧ ░	▧ ░	▧ ░	▧ ░	░	░	░			4-6	juniper, p. pine 4.0 ha/pr., aspen 5.8 ha/pr.
SPTH	13	Williamson's sapsucker	L			░	░	▧ ░	▧ ░	▧ ░	░	░	░	░		3-7	nesting terr. 4.0 ha (10.0 ac)/pr. (≤20 ha/pr.
PIVI	13	hairy woodpecker	L	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	3-6	juniper, p. pine 10.1 ha/pr., aspen 7.5 ha/pr.
SEPL	7	broad-tailed hummingbird[2]						▧ ░	▧ ░	░						2	aspen 3.8 ha/pr.
SERUF	11	rufous hummingbird[2]					▧ ░	▧ ░	▧ ░	░						2	
STCAL	7	calliope hummingbird	L					░	▧ ░	▧ ░	░					2	

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
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			■	■								● ■	● ■	● ■	● ■	● ■	● ■	● ■	□	□	□	□	0

Reproduction orientations
▧, ● Primary (≥40%)
▨, ○ Secondary (<40%)
Feeding orientations L – Low
░, ■ Primary (≥40%) M – Medium
▓, Secondary (<40%) H – High

Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				Activity/seasonal occurrence													
CAAN	7	Anna's hummingbird	L														
MEAL	16	belted kingfisher	L	░	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	5-8	
CHMI	6	common nighthawk	M					░	▧ ░	▧ ░	░	░				2/clutch; 1 clutch/yr	≃ 20.2 ha/pr. (50 ac)
CYNI	4	black swift	L					▧ ░	▧ ░	░	░	░				1	
CHVA	14	Vaux's swift	L					▧ ░	▧ ░	░	░	░				3-5	
AESA	4	white-throated swift	L					▧ ░	▧ ░	░	░					3-6	
ARAL	7	black-chinned hummingbird[2]						▧ ░	▧ ░	░						2	
ATCU	15	burrowing owl	L			░	▧ ░	▧ ░	▧ ░	░	░	░	░			5-9	loosely colonial
ASOT	11	long-eared owl	L	░	░	░	▧ ░	▧ ░	░	░	░	░	░	░	░	3-8	
ASFL	5	short-eared owl	L			░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░		4-9	
AEAC	14	saw-whet owl	L	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	4-7	

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
			■	■								● ■	● ■	● ■	● ■	● ■	● ■	● ■	□	□	○ □	□	0
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			□	□		□		□						● ■	● ■	● ■	● ■	● ■		○ □	○ □	□	0

Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

▆, □ Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
PHNU	6	poorwill	L					■	●■	●■	■	■				2	
TYAL	14	barn owl	L	■	■	■	●■	●■	○■	○■	○■	○■	○■	■	■	5-7	h.r. ≥202 ha (500 ac)/pair
OTAS	14	common screech owl	L	■	■	■	●■	●■	●■	■	■	■	■	■	■	4-5	
OTFL	14	flammulated owl				■	●■	●■	●■	■	■	■				2-4	nesting terr. 6.1-12.1 ha (15-30 ac)
BUVIR	12	great horned owl	M	■	●■	●■	●■	●■	■	■	■	■	■	■	■	2-3	h.r. 1,214 ha (3,000 ac)
GLGN	14	pygmy owl	L	■	■	■	●■	●■	●■	■	■	■	■	■	■	3-4	
STCAS	3	Caspian tern	L						■	■	■	■	■			2-3	
CHNI	3	black tern	L				■	●■	●■	■	■	■				3	
COLI	4	rock dove	L	■	■	■	●■	●■	●■	■	■	■	■	■	■	2	
ZEMA	11	mourning dove	M	■	■	■	■	●■	●■	●■	●■	●■	■	■	■	2/clutch; 1 clutch	density 7-10 prs./40.5 ha (juniper)
COAM	8	yellow-billed cuckoo	L					●■	●■	■	■	■				2-4	

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahogany/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
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	□	■	■	■	■	■	■	● ■	■	■	■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	□	○ □	○ □	● ■	+
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			□	□												● ■	● ■	● ■	■	○ ■	○ □	○ □	0
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																● ■	● ■	● ■	● ■	○ □	○ □	□	0

Reproduction orientations
▨, ● Primary (>40%)
▧, ○ Secondary (<40%)

Feeding orientations
░, ■ Primary (>40%)
▓, Secondary (<40%)

L – Low
M – Medium
H – High

Activity/seasonal occurrence

Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
LACA	3	California gull	L				▨	▨	▨							2-3	
						░	░	░	░	░	░	░	░	░			
LADE	3	ring-billed gull[2]					▨	▨	▨							2-4	
						░	░	░	░	░	░	░	░	░			
LAPI	3	Franklin's gull	L					▨	▨							3	
						░	░	░	░	░	░	░	░	░			
LAPH	3	Bonaparte's gull[2]														2-4	
						░	░	░	░	░	░	░	░	░			
STFO	3	Forster's tern	L				▨	▨								3-4	
							░	░	░	░	░	░	░				
REAM	3	American avocet	L					▨	▨							3-4	
							░	░	░	░	░	░					
HIME	3	black-necked stilt	L					▨	▨								
							░	░	░	░	░	░					
STTRI	3	Wilson's phalarope	L					▨	▨							4	
							░	░	░	░	░	░					
LOLO	3	northern phalarope[2]														4	
								░	░	░	░	░	░				
LAAR	3	herring gull[2]														2-3	
				░	░	░							░	░	░		
CABA	3	Baird's sandpiper[2]														4	
						░	░	░	░	░	░	░	░	░			

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
			■	■												● ■	● ■	● ■	□	□	□	□	0
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			■	■												● ■	● ■	● ■	□	□		□	0
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Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations — L – Low

░, ■ Primary (>40%) — M – Medium

▓, Secondary (<40%) — H – High

				Activity/seasonal occurrence													
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
CAMI	3	least sandpiper[2]				░	░	░	░	░	░	░	░	░		4	
CAMAU	3	western sandpiper[2]					░	░	░	░	░	░	░	░		4	
LISC	3	long-billed dowitcher[2]					░	░	░	░	░	░				4	
LIFE	3	marbled godwit[2]															
TRSO	7	solitary sandpiper[2]					░	▧ ░	▧ ░	▧ ░	░	░	░	░		4	
TRME	3	greater yellowlegs				░	░	▨ ░	▨ ░	░	░	░	░	░		4	
TRFL	3	lesser yellowlegs[2]				░	░	░				░	░	░		4	
CASE	3	willet[2]					░	▧ ░	▧ ░	░	░	░				3-4	
CAMEL	3	pectoral sandpiper[2]				░	░	░				░	░	░		4	
CHVO	3	killdeer	L	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	4	
CHMO	3	mountain plover[2]		░	░	░	░					░	░	░	░	3	

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
																						□	0
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uses blackbird nests																						○ □	0
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																						● ■	0

Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

█, □ Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				January	February	March	April	May	June	July	August	September	October	November	December		
CAGA	3	common snipe	L	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	4	
NUAM	5	long-billed curlew	M			░	▧ ░	▧ ░	▧ ░	▧ ░	░	░				4	
ACMA	3	spotted sandpiper	L				░	▧ ░	▧ ░	▧ ░	░	░	░			4	
RALI	3	Virginia rail	L		░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░		5-12	
POCAR	3	sora	L			░	░	▧ ░	▧ ░	░	░	░	░			6-15	
FUAM	3	American coot	L		░	░	░	▧ ░	▧ ░	░	░	░	░	░	░	8-12	
CHSEM	3	semi-palmated plover[2]								░	░						
CHALE	3	snowy plover					▧ ░	▧ ░	▧ ░	░	░	░	░			2-3	
ORPI	5	mountain quail	L	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	5-15	≃ breeding density of 1 bird/3 ac (near water)
ALCH	4	chukar	L	░	░	░	░	▧ ░	▧ ░	░	░	░	░	░	░	8-15	density 20 ac/bird
PEPER	5	gray partridge	L	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	10-22	h.r. covey 1/8-1/4 mi; density 10-30 ac/bird (nesting)

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
			● ■	● ■												● ■	○ □	○ □	● ■	○ □	○ □	□	0
≥ 2 ha (5 ac) traditional sites/pair	□		■	■	● ■	● ■	□	● ■								● ■	● ■	● ■	○ □	○ □	□	□	0
			□	□												● ■	● ■	● ■	□	○ □	○ □	○ □	0
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water critical, each water point has effective area of 2,000 ac					■	● ■	■	● ■	● ■	■	■	□	■	□	□	■	■				□	● ■	0
	□		■	■		● ■	□	● ■	□	□	□	□	□			● ■	● ■	● ■		○ □	○ □	□	0

Reproduction orientations

▨, ● Primary (>40%)

▧, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

▇, □ Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				Activity/seasonal occurrence													
PHCOL	5	ring-necked pheasant	L	░	░	░	░	▨ ░	▨ ░	░	░	░	░	░	░	6-14	
GRCA	3	sandhill crane		░	░	░	░	▨ ░	▨ ░	░	░	░	░	░	░	2	
FASP	14	American kestrel	M	░	░	░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	3-5	
DEOB	5	blue grouse	L	░	░	░	▨ ░	▨ ░	░	░	░	░	░	░	░	5-10	1.5-5.0 ac/male/ nesting territory
BOUM	5	ruffed grouse	L	░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	░	8-14	aspen 8.3 ha/pr.; brood range ≤ 125 ac
CEUR	5	sage grouse	M	░	░	░	▨ ░	▨ ░	░	░	░	░	░	░	░	7-13; avg. 7.13 in Oregon	1 lek/5.7 mi^2; ≤12.5 ♂'s/mi^2, 30-50/mi^2
LOCA	5	California quail	L	░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	░	10-17	≃ breeding density of 1 bird/2 ac (occupied area)
CICY	5	northern harrier	L			░	▨ ░	▨ ░	▨ ░	▨ ░	░	░				4-6	
PAHA	12	osprey				░	▨ ░	▨ ░	▨ ░	▨ ░	░	░				2-4	
FAME	4	prairie falcon	M			░	▨ ░	▨ ░	▨ ░	▨ ░	░	░				3-6	
FAPE	4	peregrine[2]		░	░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	2-4	

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/ bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
			□	□		□		● ■	□		□	□	□	□		● ■	● ■	● ■		□	□	□	0
			● ■	■												● ■	□	● ■	● ■	● ■	□	□	0
			■	■		■		■				● ■		● ■	● ■	● ■	● ■	● ■	■	□	□	● ■	+
									□	□	□	● ■	● ■	● ■	● ■	● ■	● ■	● ■		□	□		0
density ≤ ♂/8-94 ac									■	■	■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	□	□	□	□	0
one protected lek/population, density 10/640 ac					■	● ■	■	● ■	□	□	□	■	■		■	■	■	■		□	□	□	0
								● ■	□	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■		□	□	□	+
	□	□	● ■	● ■	□	□	□	● ■	■	□	□	□	□			● ■			● ■	● ■		□	0
																● ■	● ■	● ■		● ■	● ■		0
0.4 km (0.25 mi) undisturbed cliff/pair	● ■	□	■	■	■	● ■	● ■	■	□	□	□	■	□	□	■	■	■	■		□	□	● ■	0
0.8 km (0.5 mi) undisturbed cliff/pair																						● ■	0

Reproduction orientations

▨, ● Primary (>40%)

▧, Secondary (< 40%)

Feeding orientations

░, ■ Primary (>40%)

█, □ Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
FACO	11	merlin[2]		░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	░	3-6; avg. 4-5	
BUSW	7	Swainson's hawk	M			░	▨ ░	▨ ░	▨ ░	░	░	░	░			2-4	
BULA	4	rough-legged hawk[2]		░	░	░	░						░	░	░	2-6	
BUREG	4	ferruginous hawk	M		░	░	▨ ░	▨ ░	▨ ░	░	░	░	░			3-8	
AQCH	12	golden eagle	M	░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	░	1-3	
HALE	12	bald eagle[2]		░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	░	2-3	
CAAU	4	turkey vulture	M		░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░		1-3	
ACGE	11	northern goshawk		░	░	░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	3-5	nesting terr. 5.8 km (3.6 mi) radius
ACST	11	sharp-shinned hawk	L	░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	░	3-5	
ACCO	11	Cooper's hawk	L	░	░	░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	░	3-5	
BUJA	12	red-tailed hawk	M	░	░	▨ ░	▨ ░	▨ ░	▨ ░	▨ ░	░	░	░	░	░	2-4	nesting terr. 1.3-7.8 km^2 (0.5-3.0 mi^2)

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
														● ■	● ■	● ■	● ■	● ■	● ■	●	●	○ □	0
nesting home range 1 pair per 6.7 km^2			□	□	□	■	■	● ■	□	■	■	● ■	■	● ■	● ■	● ■	● ■	● ■		○ □	○ □	□	+
																						□	+
	○ □		□	□	■	● ■	● ■	● ■	■	□	□	● ■	■	● ■	● ■	● ■		● ■		□		● ■	0
	■	■	■	■	■	■	■	● ■	■	■	■	● ■	● ■	■	■	● ■	● ■	● ■	■	□	□	● ■	+
																						□	+
	■	■	■	■	■	● ■	■	● ■	■	■	■	● ■	■	■	■	■	■		■	□	□	● ■	+
12.1 ha core nesting area within a 10,118 to 15,379 ha nesting terr. (30 ac/25,000-38,000 ac)/pair														● ■	■	● ■	● ■	● ■		○ □	○ □	○	0
12.1 ha core nesting area within a 10,118 to 15,379 ha nesting terr. (30 ac/25,000-38,000 ac)/pair			□	□				□	□	□	□	■	□	● ■	● ■	● ■	● ■				○ □	□	0
12.1 ha core nesting area within a 10,118 to 15,379 ha nesting terr. (30 ac/25,000-38,000 ac)/pair			□	□				○ □	■	■	■	■	■	● ■	● ■	● ■	● ■				○ □	□	0
	□	□	■	■	■	■	■	● ■	■	■	■	● ■	● ■	● ■	● ■	● ■	● ■	● ■		○ □	○ □	○ □	+

Reproduction orientations

▧, ● Primary (>40%)

////, Secondary (<40%)

Feeding orientations L – Low

░, ■ Primary (>40%) M – Medium

█, Secondary (<40%) H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
CLHY	3	oldsquaw[2]		█	█									█	█		
OXJA	3	ruddy duck	L	░	░	░	░	░	░	▧ ░	▧ ░	░	░	░	░	6-10	
LOCU	14	hooded merganser[2]		░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	6-12	
MEMER	14	common merganser	L	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	6-12	
MESE	3	red-breasted merganser[2]		░	░	░								░	░	8-10	
AYAF	3	lesser scaup	L	░	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	9-12	
BUCL	3	common goldeneye[2]		░	░	░	░	░						░	░	5-19; avg. 8-12	
BUIS	14	Barrow's goldeneye		░	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	6-15; avg. 10	
BUALBE	14	bufflehead[2]		░	░	░	░	░	▧ ░	▧ ░	░	░	░	░	░	6-14; avg. 10-12	
SOSP	3	King eider[2]		█	█									█	█		
AISP	14	wood duck			░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░		10-15	

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
																						□	0
																● ■		● ■		● ■			0
																						□	0
																● ■	● ■			□	● ■	□	0
																						□	0
																● ■		● ■	● ■			□	0
																						□	0
																● ■	● ■	● ■	■	■	■	□	0
																						□	0
																						□	0
≥0.8 ha (2 ac) of suitable marsh/pair																● ■	□	□	● ■	● ■	□	□	0

Reproduction orientations

▚, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

█, Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				January	February	March	April	May	June	July	August	September	October	November	December		
AYAM	3	redhead					■	● ■	● ■	● ■	■	■				10-15	
AYCO	3	ring-necked duck	L					● ■	● ■	● ■	■	■	■	■		6-12	
AYVA	3	canvasback		■	■	■	■	○ ■	○ ■	○ ■	■	■	■	■	■	7-9	
AYMA	3	greater scaup[2]		■	■	■							■	■	■	7-10	
ANCR	3	green-winged teal	L	■	■	■	■	● ■	● ■	● ■	■	■	■	■	■	10-12	
ANDIS	3	blue-winged teal	L			■	■	● ■	● ■	● ■	■	■	■	■	■	6-12	
ANCY	3	cinnamon teal	L					● ■	● ■	● ■	■	■	■	■		6-12	
ANAMEO	3	American wigeon	L	■	■	■	■	● ■	● ■	● ■	■	■	■	■	■	6-12	
ANCL	3	northern shoveler	L			■	■	● ■	● ■	● ■	■	■				6-14	
CHCA	3	snow goose[2]		■	■								■	■	■	4-12; avg. 5-7	
CHRO	3	Ross' goose[2]		■	■								■	■	■	3-9; avg. 5-7	

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
0.2 ha (0.5 ac) emergent, riparian cover/pair																● ■	□	● ■		● ■		□	0
0.2 ha (0.5 ac) emergent, riparian cover/pair			■	□												● ■	□	● ■	● ■	■	□	□	0
																● ■	□	● ■		● ■		□	0
																						□	0
0.2 ha (0.5 ac) emergent, riparian cover/pair			■	□	○ □		○ □	○ □								● ■	■	● ■	□	■	□	□	0
0.2 ha (0.5 ac) emergent, riparian cover/pair			■	□	○ □		○ □	○ □								● ■	■	● ■	□	■	□	□	0
0.2 ha (0.5 ac) emergent, riparian cover/pair			■	□	○ □		○ □	○ □								● ■	□	● ■	□	■	□	□	0
0.2 ha (0.5 ac) emergent, riparian cover/pair			■	□	○ □		○ □	○ □								● ■	□	● ■	● ■	■	□	□	0
0.2 ha (0.5 ac) emergent, riparian cover/pair			■	□	○ □		○ □	○ □								● ■	□	● ■	● ■	■	□	□	0
																						□	0
																						□	0

Reproduction orientations

▚, ● Primary (>40%)

▨, Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

▓, □ Secondary (<40%)

L – Low

M – Medium

H – High

				Activity/seasonal occurrence													
Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
ANPL	3	mallard	L	░	░	░	▚ ░	▚ ░	▚ ░	▚ ░	░	░	░	░	░	8-10	
ANSTR	3	gadwall	L	░	░	░	░	▚ ░	▚ ░	▚ ░	░	░	░	░	░	7-13	
ANAC	3	common pintail	L			░	░	▚ ░	▚ ░	▚ ░	░	░	░			6-12	
IXEX	3	least bittern	L				▚ ░	▚ ░	▚ ░	░	░	░	░			4-7; avg. 4-5	
PLCH	7	white-faced ibis[2]		░	░						░	░	░	░	░	3-5	
OLCO	3	whistling swan[2]		░	░	░	░					░	░	░	░	2-7; avg. 4-5	
BRCA	3	Canada goose		░	░	▚ ░	▚ ░	▚ ░	▚ ░	▚ ░	▚ ░	░	░	░	░	4-10; avg. 5-6	
ANAL	3	white-fronted goose[2]		░	░								░	░	░	4-7; avg. 5-6	
BUST	7	green heron					▚ ░	▚ ░	▚ ░	░	░	░	░			3-6; avg. 4-5	
CAAL	12	common egret	L							░	░	░	░			3-5	colonial nester
BUIB	7	cattle egret	L							░	░	░	░				colonial nester

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush/bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
0.2 ha (0.5 ac) emergent, riparian cover/pair			■	□	□		□	○								● ■	● ■	● ■	● ■	● ■		□	0
0.2 ha (0.5 ac) emergent, riparian cover/pair			■	□	□		□	○ □								● ■	● ■	● ■	● ■	● ■	□		0
0.2 ha (0.5 ac) emergent, riparian cover/pair			■	□	○ □		○ □	○ □								● ■	● ■	● ■	● ■	● ■	□	□	0
			□													● ■	□	● ■	■	□			0
																□	□	□	□	□		□	0
																■	□	■	□	■		□	0
																● ■	○ □	● ■		● ■		○	0
																						□	0
																● ■	● ■	● ■		● ■		□	0
0.4 to 4.0 ha (1-10 ac)/colony	□		■	■				○ □				●		●	●	● ■	● ■	● ■	■	■		□	0
	□		■	■				○ □						● ■	● ■	● ■	● ■	● ■	■	■		□	0

Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%) L – Low

M – Medium

■, Secondary (<40%) H – High

Activity/seasonal occurrence

Letter code	Life form number	Species	Versatility rating	January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
NYNY	7	black-crowned night heron	L				▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░			3-6	colonial nester
BOLE	3	American bittern	L	░	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	3-7	
AEOC	3	western grebe	L	░	░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	3-10; avg. 5-7	nesting in dense colonies or singly
POPO	3	pied-billed grebe	L	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	3-10; avg. 5-7	1 pothole/pr
PEERY	3	American white pelican[2]									░	░	░	░		1-3; avg. 2	colonies of ≤50 nests
PHAU	3	double-crested cormorant		░	░	░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	░	3-7; avg. 3-4	colonial nester
ARHE	12	great blue heron	L	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	░	3-6	colonial nester

BIRDS

GAIM	3	common loon[2]		░	░	░	░	░					░	░	░	1-3; avg. 2	≥ one 5-ha (12-ac) lake/pr.
POGRI	3	red-necked grebe[2]											░	░	░	3-8; avg. 5-6	
POAU	3	horned grebe[2]					▧ ░	▧ ░	▧ ░	░	░	░	░	░		3-10; avg. 4-5	density 1.5-3.3 prs/km^2

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
0.4 to 4.0 ha (1-10 ac)/colony			■	■				□						● ■	● ■	● ■	● ■	● ■	■	■		□	0
			□													● ■	□	● ■	■	□		□	0
																● ■	● ■	● ■	● ■	● ■	□		0
one small pond with rush and/or tule emergents																● ■	□	● ■	● ■	● ■	□		0
requires protected island colonies						●		●								■	□	■	□	■	□		0
requires protected island colonies						●		●								○ ■	■	■	■	● ■	□	●	0
0.4 to 4.0 ha (1-10 ac)/colony	□		■	■				○ □				●		●	●	● ■	● ■	● ■	● ■	■	■	□	0
≥one 4-ha (10-ac) lake/pair																■	■	■		■			0
																■	■	■		■			0
																● ■	■	● ■	● ■	● ■	□		0

Reproduction orientations

▧, ● Primary (> 40%)

▨, Secondary (< 40%)

Feeding orientations

░, ■ Primary (> 40%)

█, Secondary (< 40%)

L – Low

M - Medium

H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence January	February	March	April	May	June	July	August	September	October	November	December	Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
PONIGR	3	eared grebe	L	░	░	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	3-9; avg. 4-5	
THEL	3	wandering garter snake	M	█	█	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▨ ░	█	█	10-20/litter; 1 litter	
SOSE	15	western ground snake	L	█	█	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	█	█	4-5/clutch; 1 clutch	
HYTO	5	night snake	L	█	█	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	█	█	2-6/clutch; 1 clutch	
CRVI	5	western rattlesnake	M	█	█	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	█	█	5-6/clutch; 1 clutch/2 yrs	h.r. ≤457 ha (1,130 ac)/individual
CHBO	5	rubber boa	L	█	█	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	█	█	2-8/litter; 1 litter	
COCONS	5	yellow-bellied racer	L	█	█	░	░	▧ ░	▧ ░	▧ ░	▧ ░	░	░	█	█	5-26; avg. 12/ clutch; 1 clutch	
MATA	5	striped whipsnake	L	█	█	░	░	░	▧ ░	▧ ░	░	░	░	█	█	3-5/clutch; 1 clutch	density .15-.22/ha
PIME	5	gopher snake	L	█	█	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	█	█	3-12/clutch; 1 clutch	
THST	3	common garter snake	H	█	█	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▨ ░	█	█	10-20/litter; 1 litter	h.r. ♂ .51 ha (1.27 ac), ♀ .26 ha (.65 ac)
UTST	5	side-blotcher lizard	M	█	█	▧ ░	▧ ░	▧ ░	▧ ░	▧ ▨ ░	▨ ░	░	░	█	█	2-8; avg. 3-5/ clutch; 1-2 clutches	h.r. 121-446 m^2 (1,302-4,799 ft^2)/ adult [4-13 ha]

Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
																● ■	■	● ■	● ■	● ■			0
≥10.1 ha (25 ac)/population			● ■	● ■			● ■	● ■	● ■			● ■		■	■	● ■	● ■	● ■	● ■	● ■			-
					● ■	● ■	● ■	● ■														● ■	-
≥20.2 ha (50 ac)/population					● ■	● ■		● ■				● ■										□	0
≥16.2 ha (40 ac)/population	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■	● ■			● ■	● ■	□				● ■	0
						○ □		○ □		○ □	○ □	○ □	○ □	● ■		● ■	● ■	● ■				□	0
>20.2 ha (50 ac)/population communal hibernacula					○ □	● ■	● ■	● ■	○ □							● ■	● ■	● ■				● ■	0
>20.2 ha (50 ac)/population								● ■														○ □	0
≥20.2 ha (50 ac)/population			● ■	○ □	○ □	○ □	● ■	● ■	○ □	○ □	○ □	● ■	○ □	○ □	○ □							○ □	0
≥10.1 ha (25 ac)/population		● ■	● ■	● ■	● ■	● ■	● ■	● ■		● ■	● ■	● ■	● ■	■	■	● ■	● ■	● ■	● ■	● ■		□	-
>2.0 ha (5 ac)/population density 75-175/ha					● ■	● ■	● ■	● ■				● ■										○ □	-

Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

█, □ Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				January	February	March	April	May	June	July	August	September	October	November	December		
PHPL	5	desert horned lizard	L	□	□	□ ■	● ■	● ■	● ■	● ○ ■	○ ■	■	□	□	□	3-9; avg. 6-8/ litter; 1 litter	general in broad areas
PHDO	5	short-horned lizard	L	□	□	● ■	● ■	● ■	● ■	● ■	● ■	■	■	■ □	□	16.7/litter; 1 litter	
EUSK	5	western skink	L	□	□	■	● ■	● ■	● ■	● ■	■	■	■	□	□		
CNTI	5	western whiptail	L	□	□	■	● ■	● ■	● ■	● ■	● ■	■	■	□	□	1-5; avg. 2-9/ clutch; 1 clutch	h.r. ♂ .07 ha, ♀ .07 ha; density = 4.0-16.0/ha
		REPTILES															
CRCO	4	collared lizard	L	□	□	□	● ■	● ■	● ■	● ■	● ■	● ■	■ □	□	□	3-12; avg. 5-7/ clutch; 1-2 clutches	♂'s very territorial
CRWI	5	leopard lizard	L	□	□	□	■	● ■	● ■	● ■	● ■	● ■	□	□	□	2-11; avg. 5.2/ clutch; 1 clutch	45-196 m (h.r.) (10/ha)
SCOC	4	western fence lizard	L	□	● □	● ■	● ■	● ■	● ■	● ■	■	■	■	□	□	4-19; avg. 8-13/ clutch; 1-3 clutches	
SCGR	5	sagebrush lizard	M	□	□	■	● ■	● ■	● ■	● ■	● ■	● ■	■	□	□	avg. 5/clutch; 1 clutch	h.r. ♂ 25 m (82 ft), = ♀ 18 m (59 ft)
BUWO	2	Woodhouse toad	L	□	□	■	● ■	● ■	● ■	● ■	● ■	■	■	□	□	approx. 100 eggs/♀	h.r. 21.8-32.3 m^2 (234.6-347.5 ft^2)/ adult
HYRE	2	Pacific treefrog	M	□	□	■	● ■	● ■	● ■	● ■	● ■	● ■	■	□	□	100 + eggs/♀	

Minimum habitat required/ pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm wet meadows	seasonally wet meadows	shadscale saltbush bunchgrass	low sagebrush bunchgrass	black greasewood grass	tall sagebrush bunchgrass	squaw apple bunchgrass	curlleaf mountain mahogany bunchgr	curlleaf mountainmahognay pinegr	juniper sagebrush bunchgrass	curlleaf mountainmahogany shrub	quaking aspen grass	quaking aspen mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and or edaphic	Manmade habitats[1]
≥12.1 ha (30 ac)/population density 1-7/ha	○				●	●	●	●	●	○	○	○										○	0
	□				■	■	■	■	■	□	□	□	□									□	
>8.1 ha (20 ac)/population						●	○	●	○		○	●										○	0
	□				□	■	□	■	□	□	□	■	□									□	
							●	○	○			●	●										0
							■	□	□			■	■			□	□	□				□	
>8.1 ha (20 ac)/population					●	●	●	●	○	○	○	●	●									○	0
					■	■	■	■	□	□	□	■	■									□	
≥2.0 ha (5 ac)/population	○				●	●	●	●	●	●	●	●	●									●	-
	□				■	■	■	■	■	■	■	■	■									■	
					●	●	●	●		○	○											●	-
					■	■	■	■	□	□	□	□	□									■	
>2.0 ha (5 ac)/population	○				○	○	○	●	●	●	●	●	●									○	+
	□				□	□	□	■	■	■	■	■	■	□	□							□	
>4.0 ha (10 ac)/population density 208/ha						○	●	●	●	●	○	●	○										0
						□	■	■	■	■	□	■	□									□	
																●		●	●	●		●	0
	■		■	■				□						■	■	■		■	■	■		■	
one 0.8-ha (2-ac) pond/ population			●					●								●		●	●	●		●	-
			■	■	□	□	□	■		□	□	□	□	■	■	■	■	■	■	■		■	

Reproduction orientations

▧, ● Primary (>40%)

▨, ○ Secondary (<40%)

Feeding orientations

░, ■ Primary (>40%)

■ Secondary (<40%)

L – Low

M – Medium

H – High

Letter code	Life form number	Species	Versatility rating	Activity/seasonal occurrence												Reproduction capacity, potential/year	Home range (h.r.)/territory (t.) size
				January	February	March	April	May	June	July	August	September	October	November	December		
RAPR	1	spotted frog	L	■	░	░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	▧ ░	░	■	■		
RAPI	2	leopard frog	L	■	░	░	▧ ░	▧ ░	░	░	░	░	░	■	■		
RACA	1	bullfrog	L	■	■	▧ ░	▧ ░	▧ ░	▧ ░	░	░	░	░	■	■		

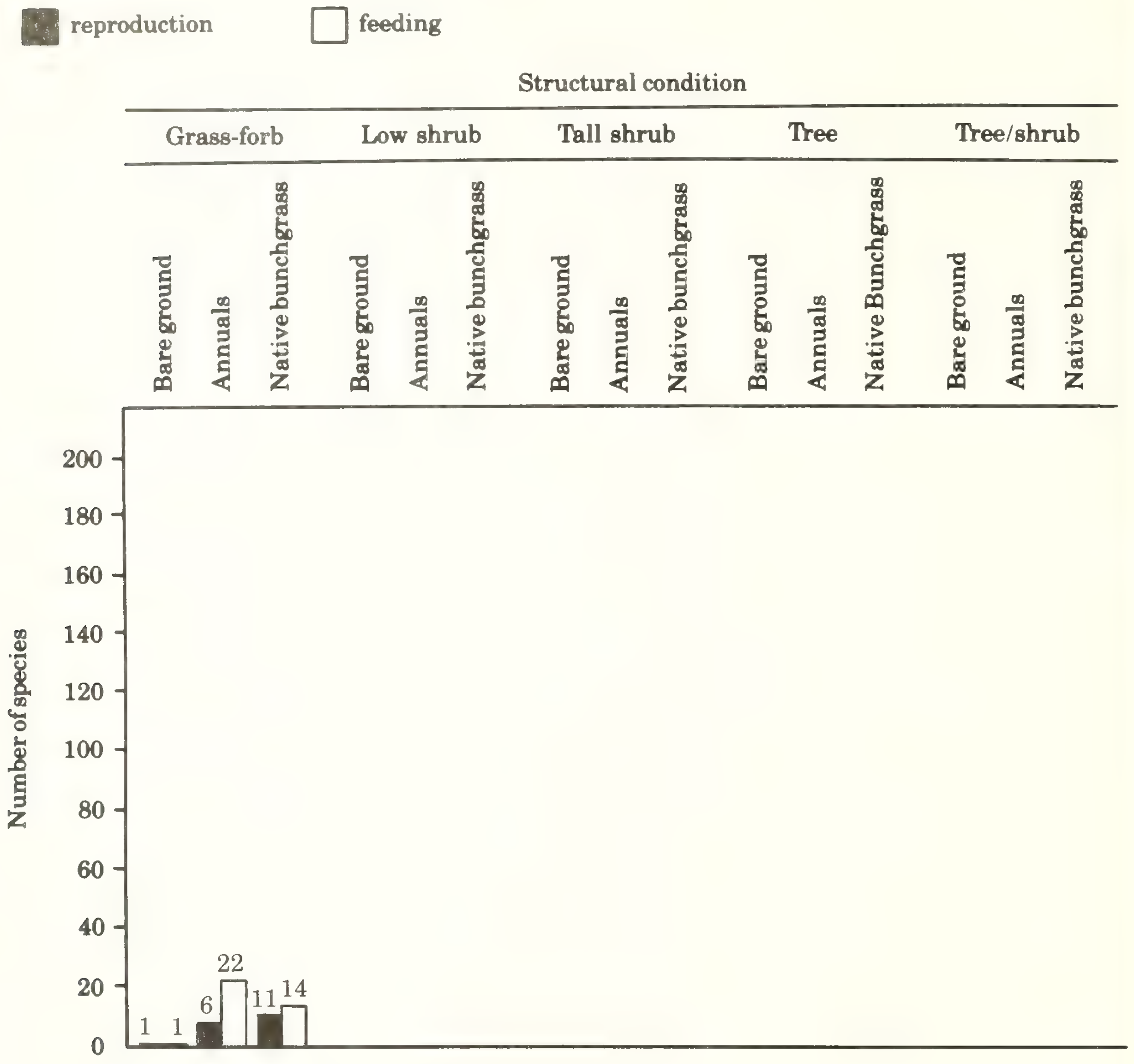
[1] Positive (+), negative (–), or neutral (0) net habitat associations (see chapter 13, Manmade Habitats, for fuller descriptions).

[2] Occurs in migration or accidentally only; see appendix 5.

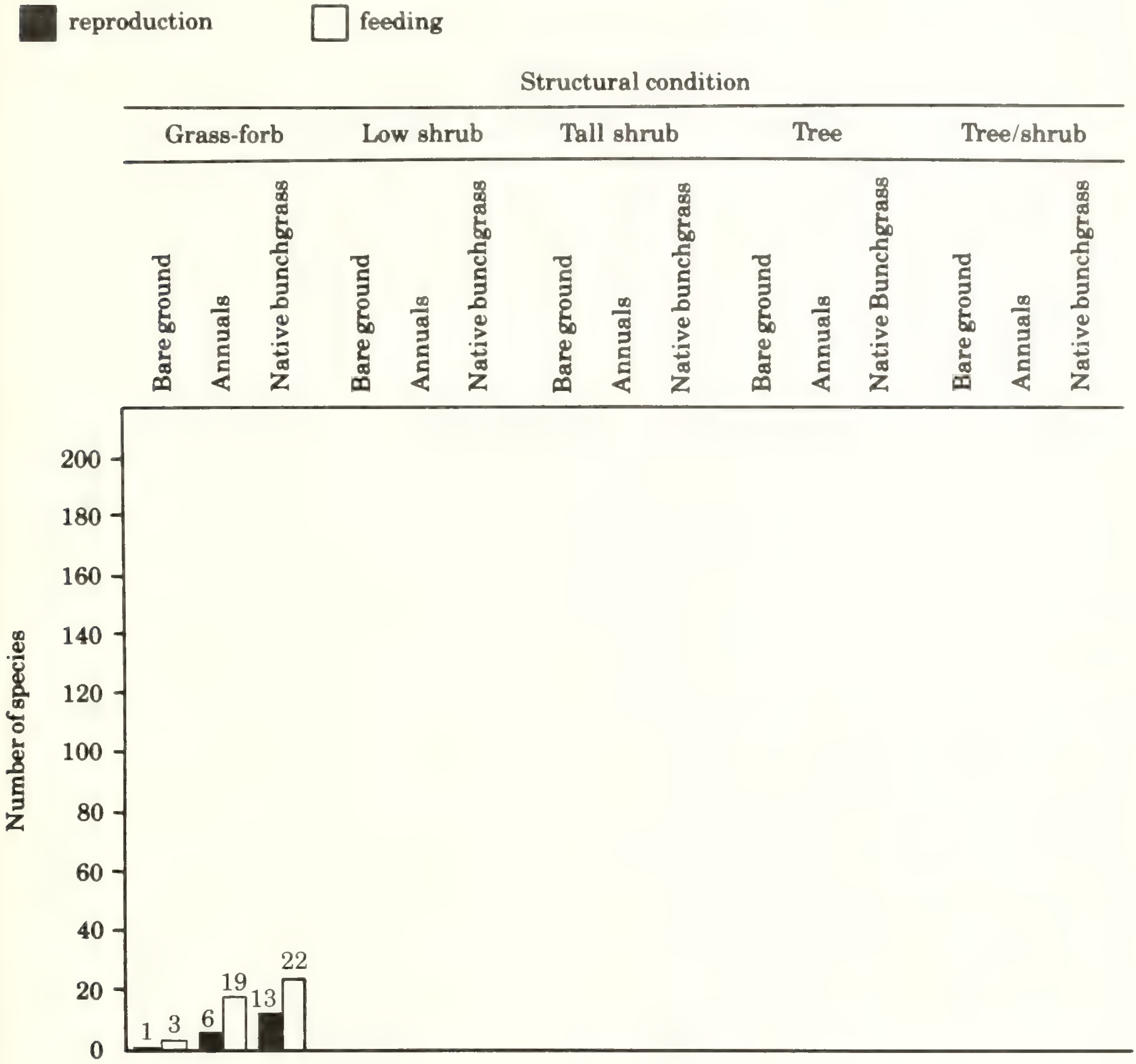
Minimum habitat required pair or population ac – acres ha – hectares	Plant community groups (habitat)																Special habitats						
	crested wheatgrass (seeded)	subalpine bunchgrass	perm. wet meadows	seasonally wet meadows	shadscale saltbush/bunchgrass	low sagebrush/bunchgrass	black greasewood/grass	tall sagebrush/bunchgrass	squaw apple/bunchgrass	curlleaf mountain mahogany/bunchgr.	curlleaf mountainmahognay/pinegr.	juniper/sagebrush/bunchgrass	curlleaf mountainmahogany/shrub	quaking aspen/grass	quaking aspen/mountain big sagebrush bunchgrass	riparian	River, creek, stream	Lake, reservoir, ponds	Marsh, bog, swamp	Standing, slow-moving water	Fast, running water	Geomorphic and/or edaphic	Manmade habitats[1]
one 0.8-ha (2-ac) pond/ population																● ■	□	● ■	● ■	● ■		■	0
one 0.8-ha (2-ac) pond/ population			□				□	□						□	□	● ■		● ■	● ■	● ■			0
one 1.6-ha (4-ac) pond/ population								□								● ■	● □	● ■	□	● ■			0

Appendix 9. Summary of wildlife species' use of plant communities by structural conditions.

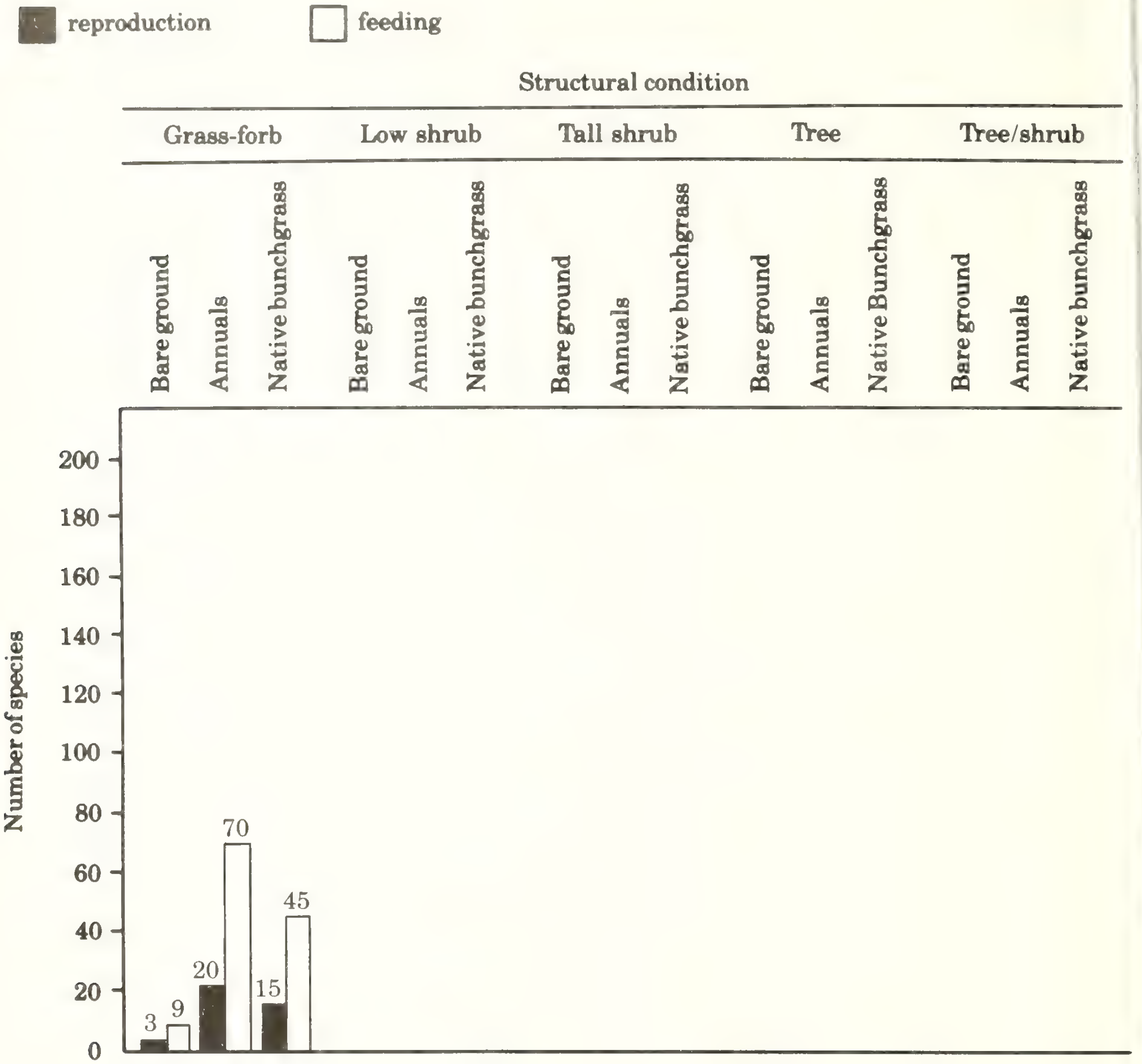
Plant community: Crested wheatgrass (seeded)



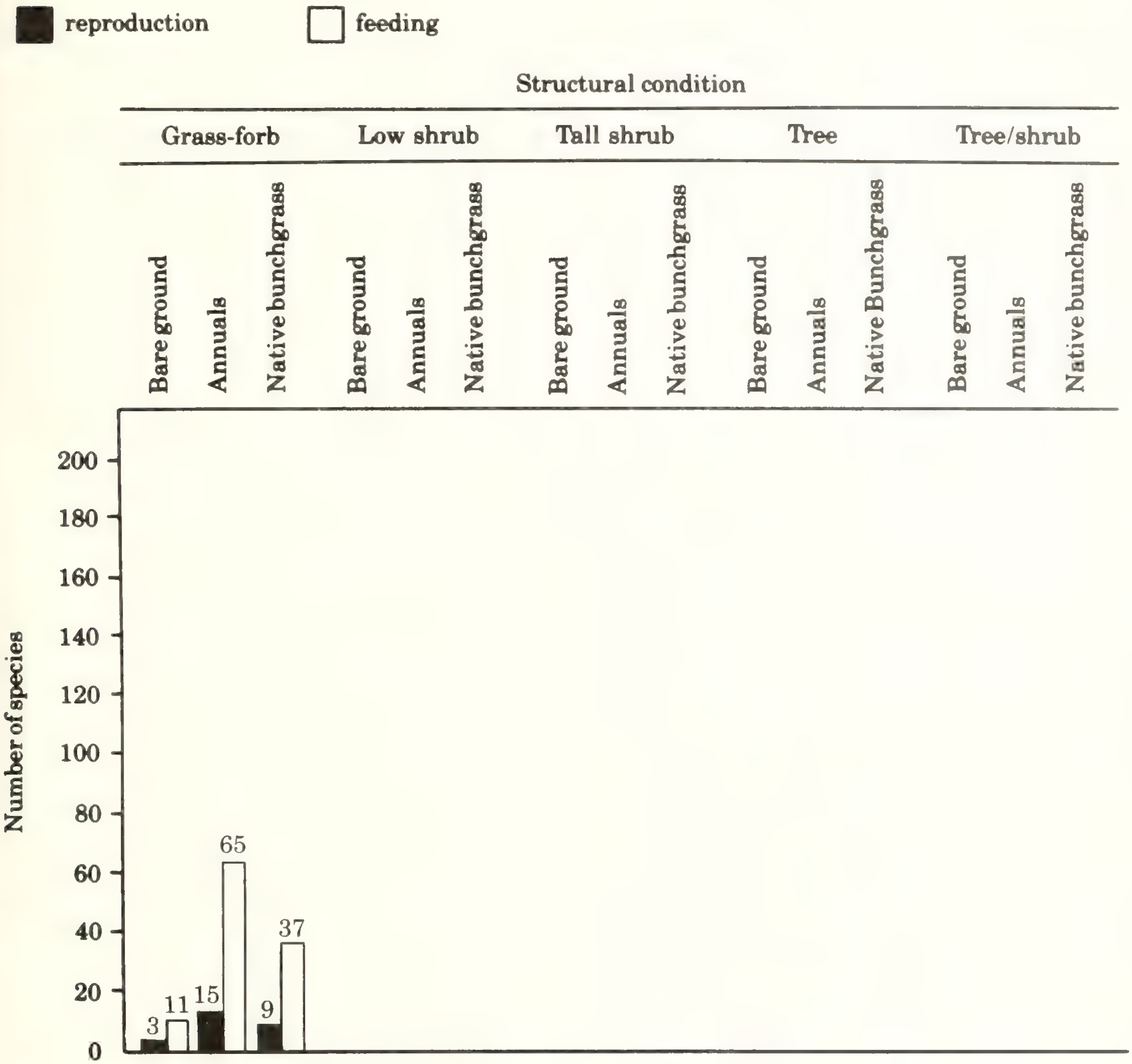
Plant community: Subalpine bunchgrass



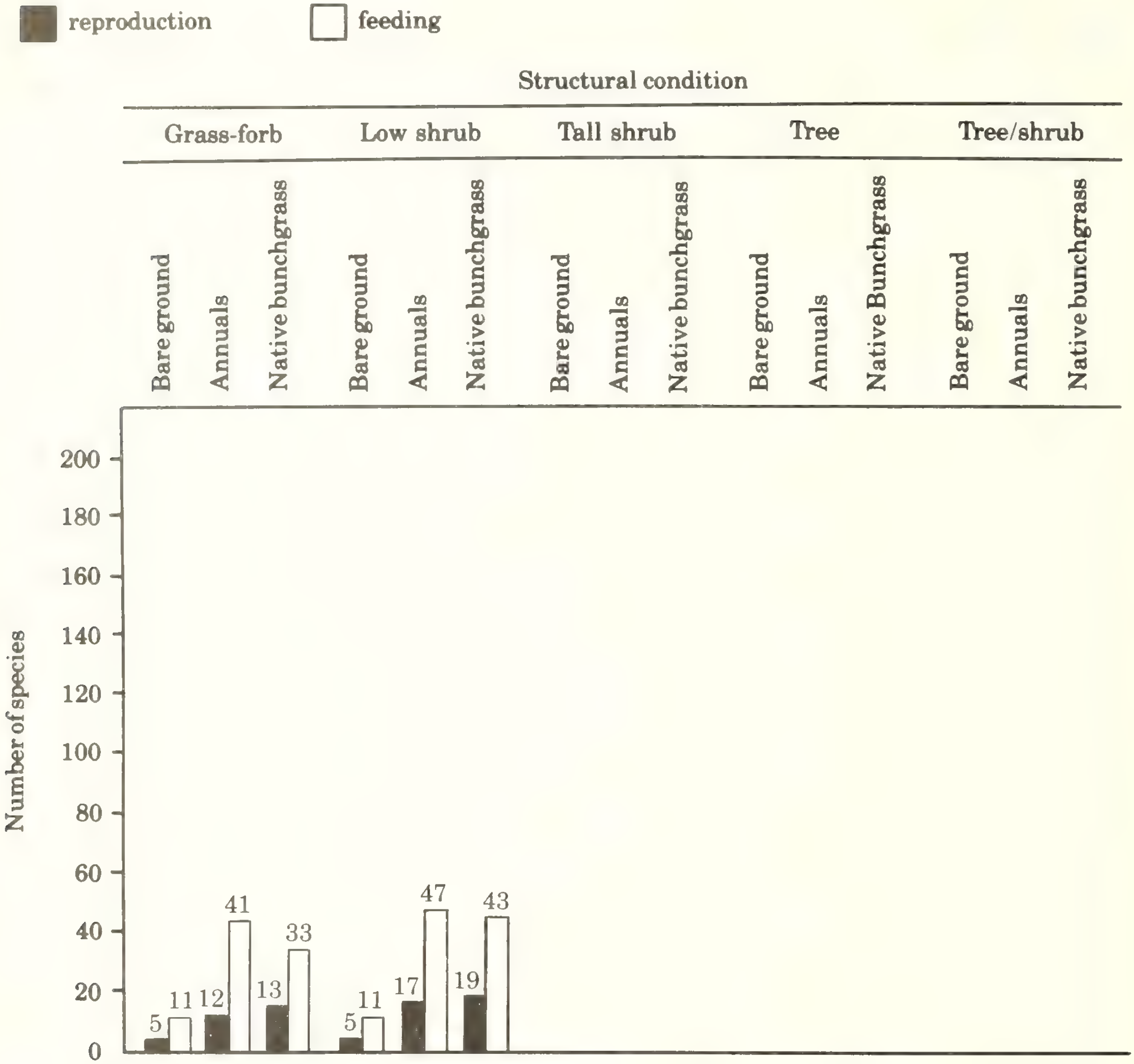
Plant community: Permanently wet meadows



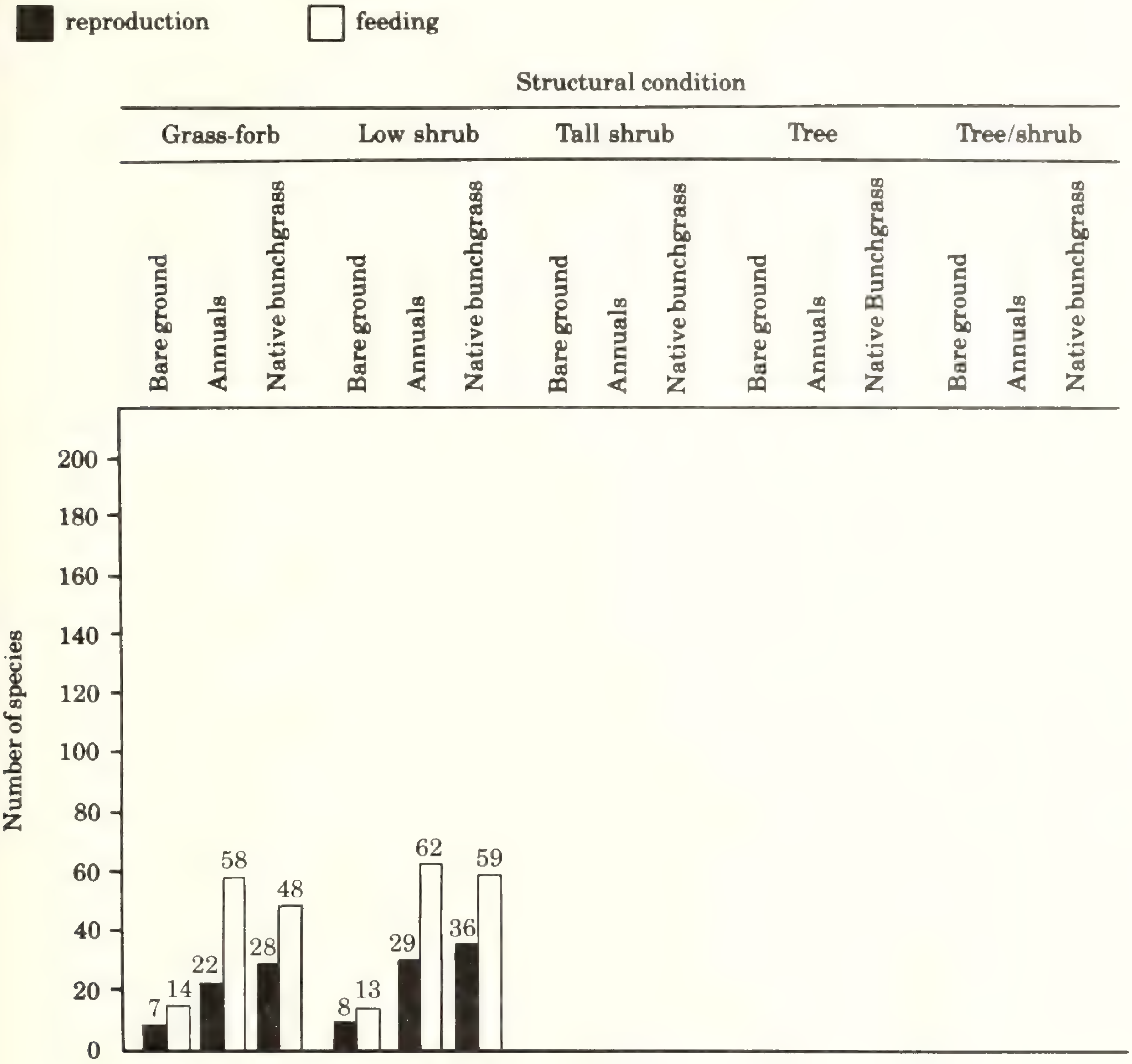
Plant community: Seasonally wet meadows



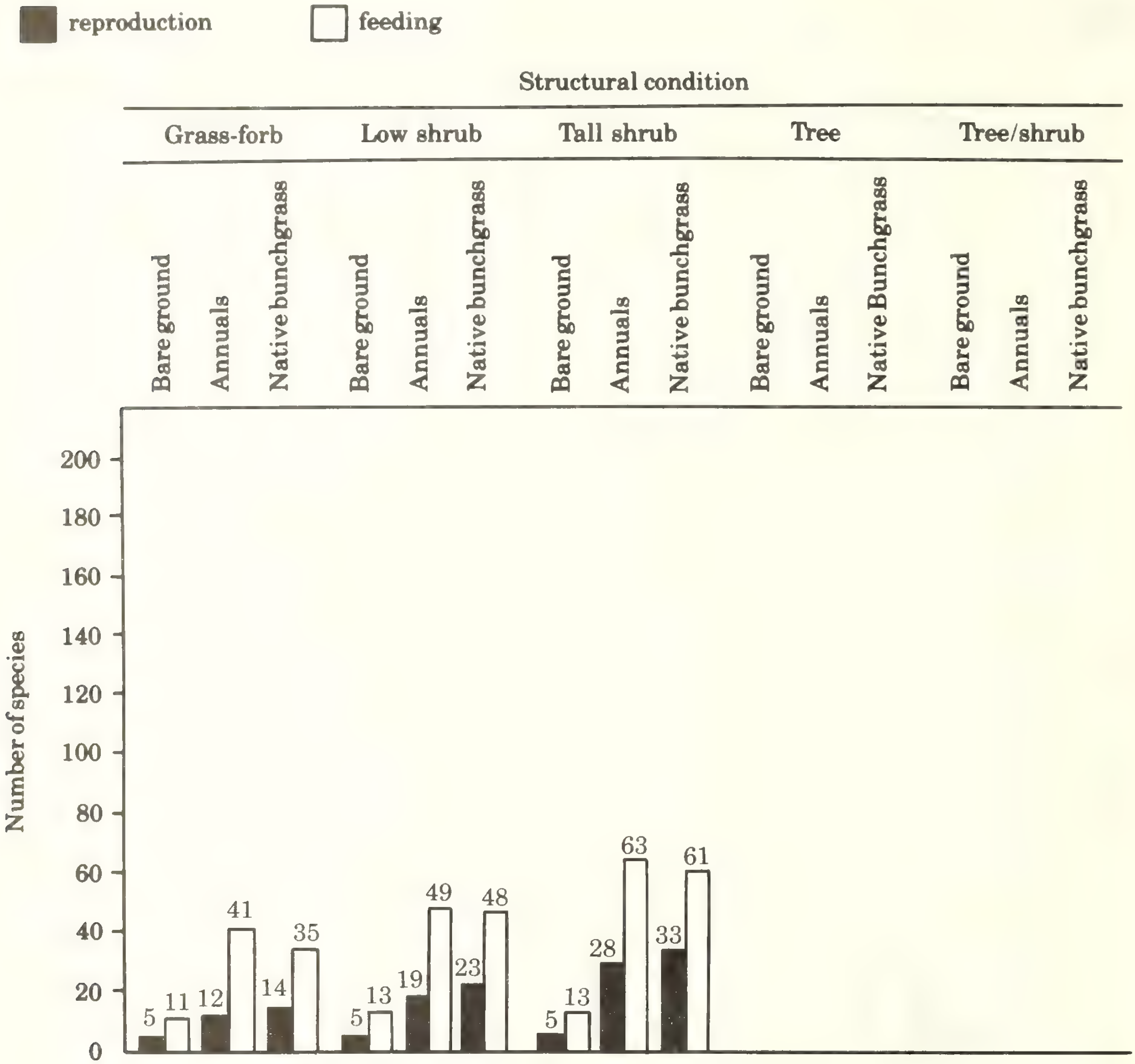
Plant community: Shadscale saltbush/bunchgrass



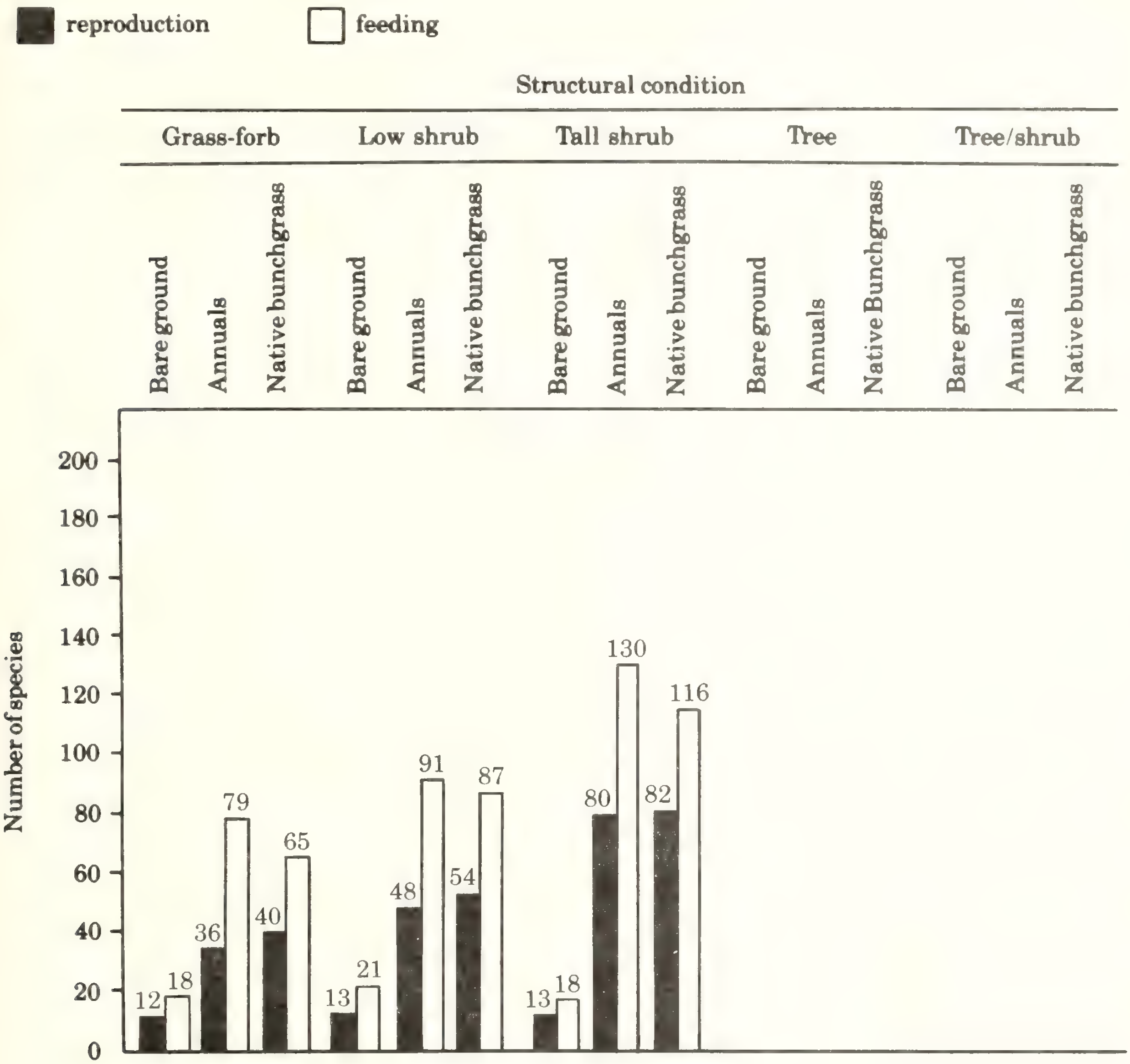
Plant community: Low sagebrush/bunchgrass



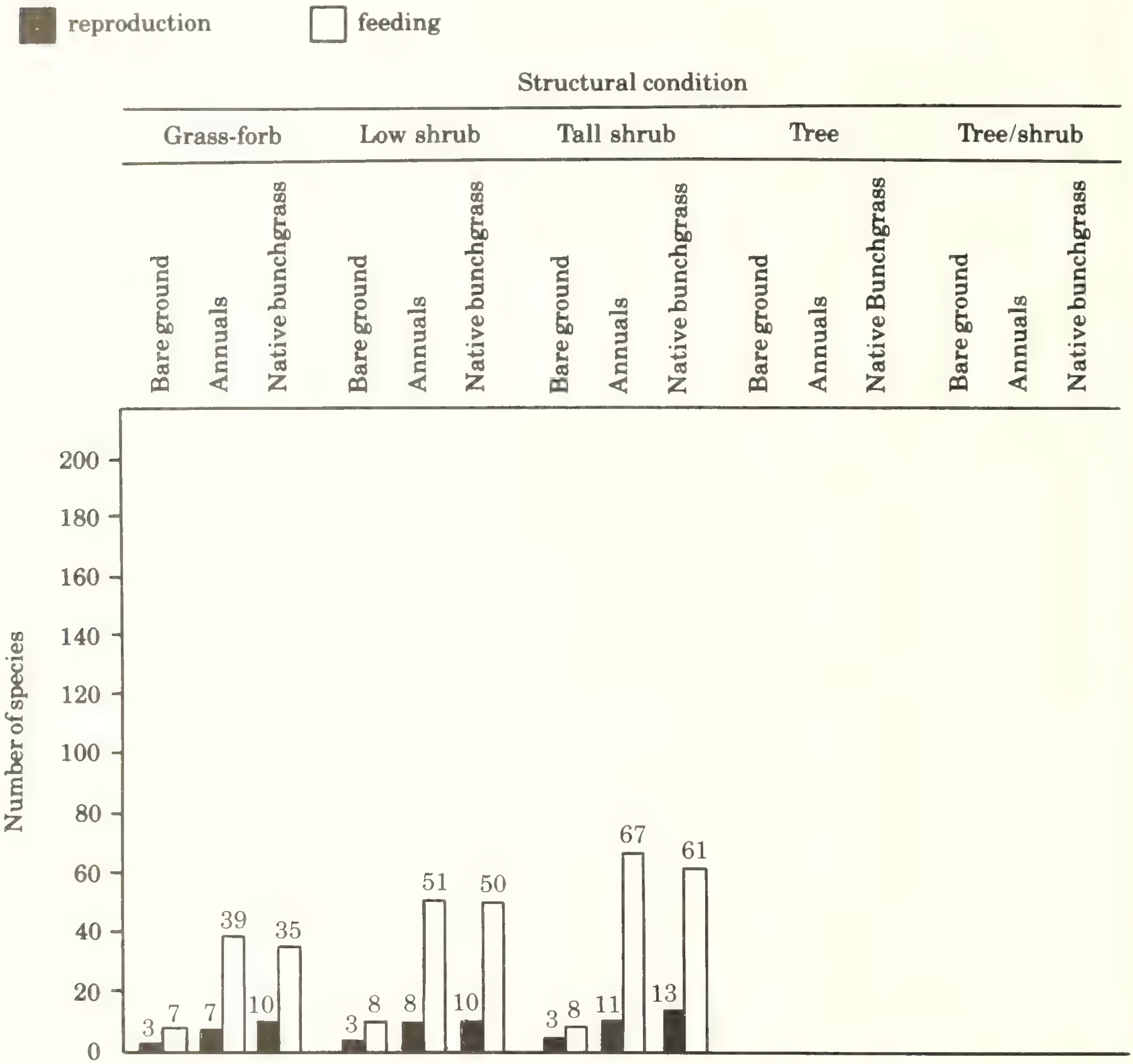
Plant community: Black greasewood/grass



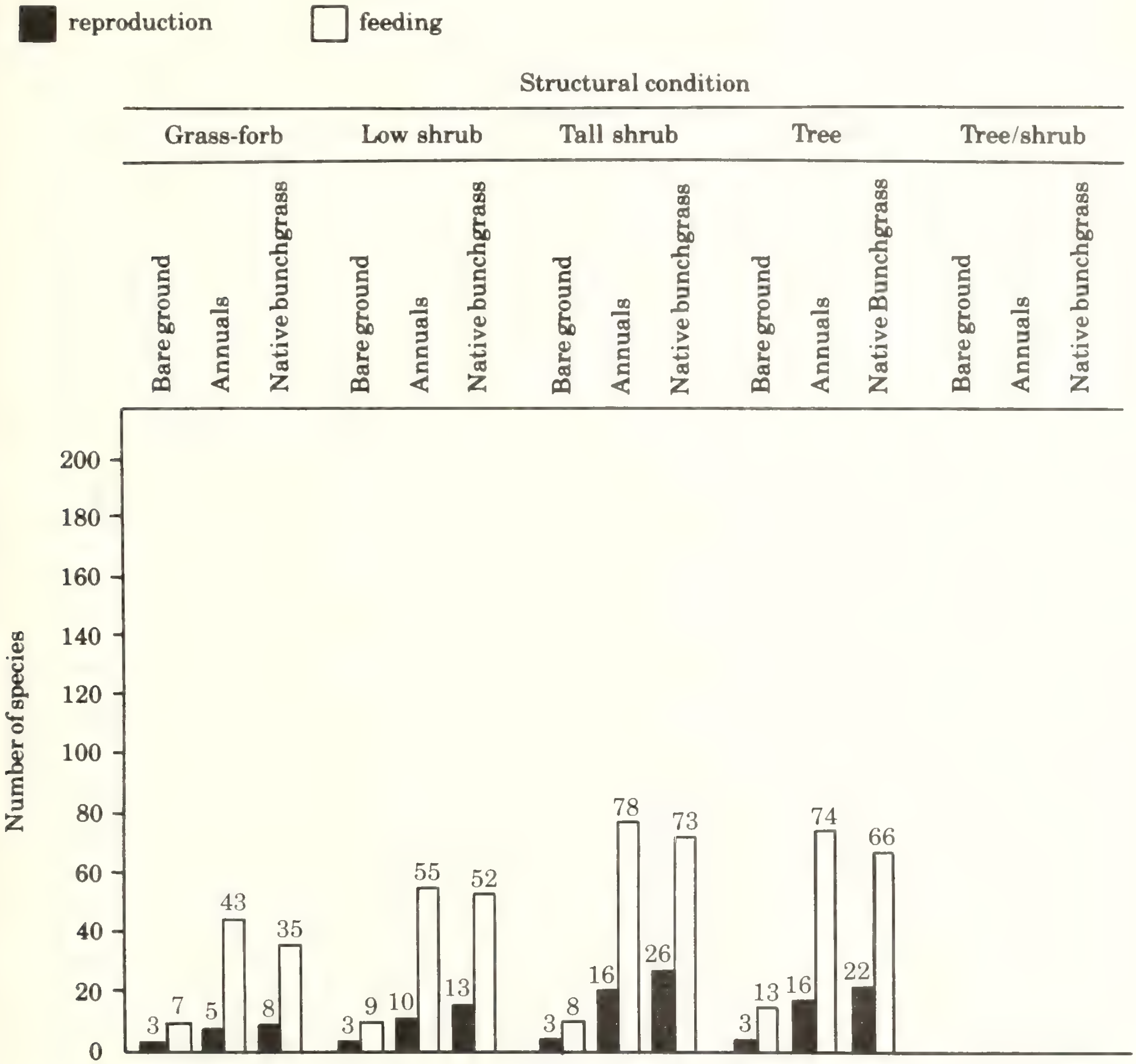
Plant community: Tall sagebrush/bunchgrass



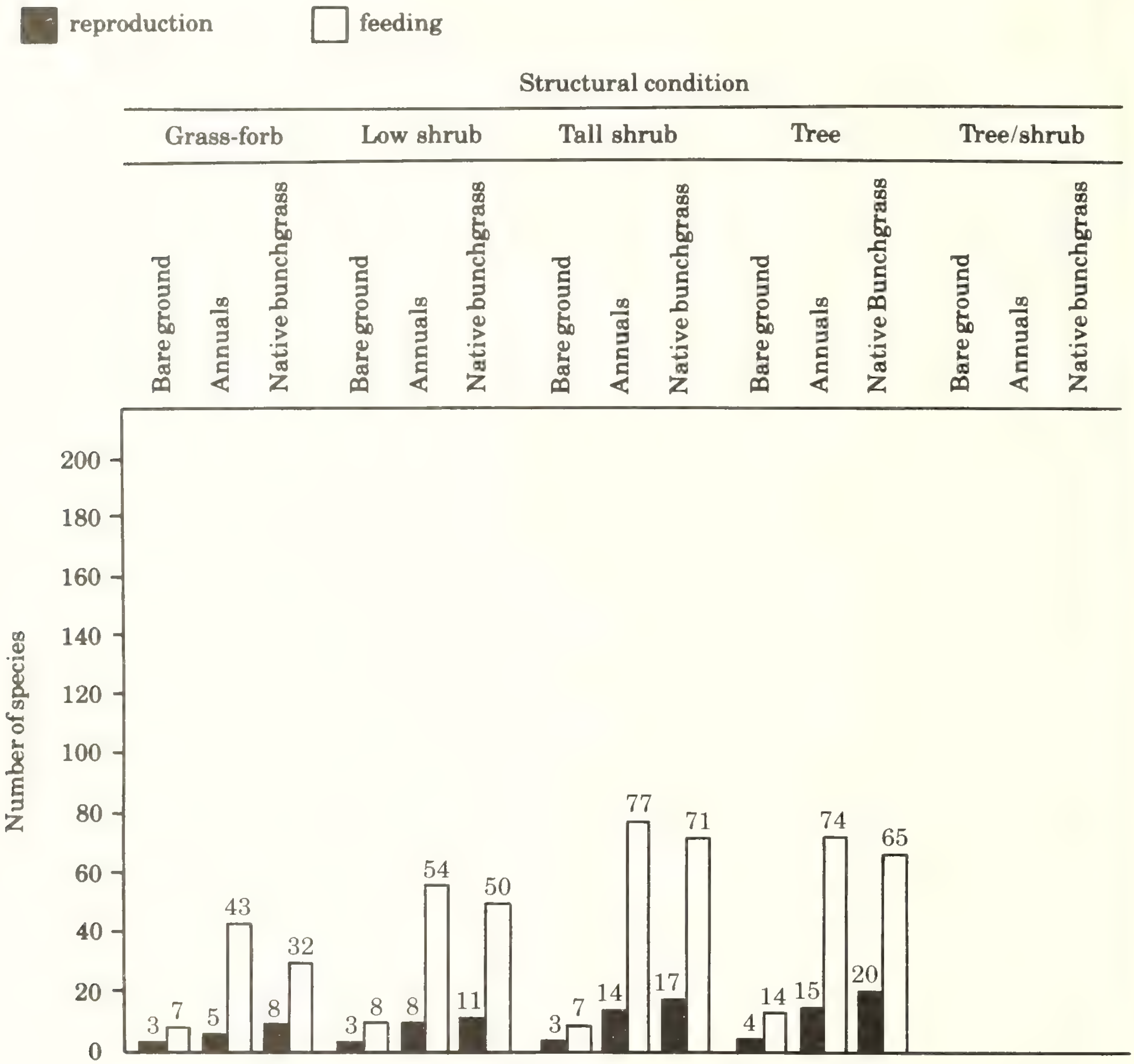
Plant community: Squaw apple/bunchgrass



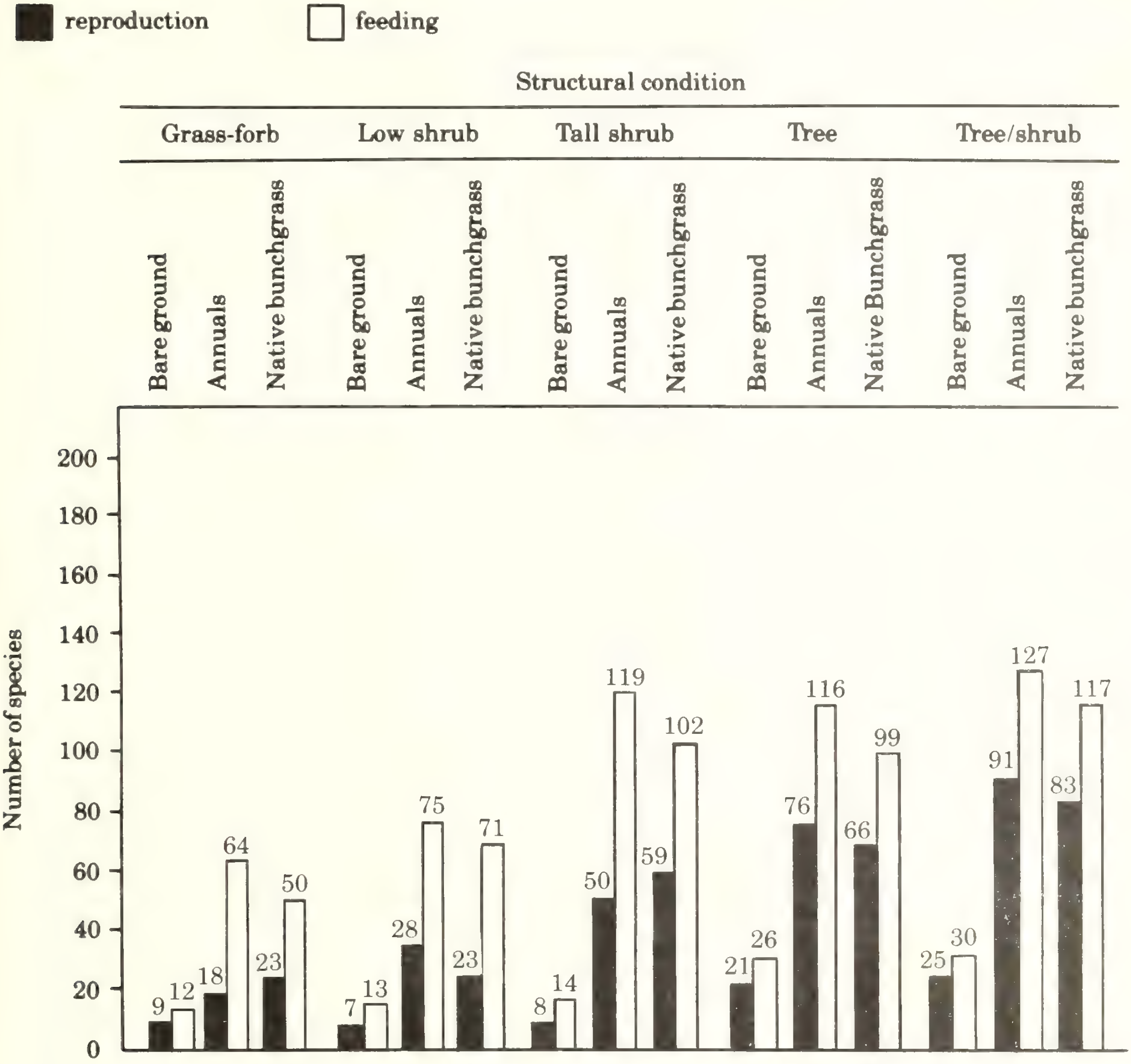
Plant community: Curlleaf mountainmahogany/bunchgrass



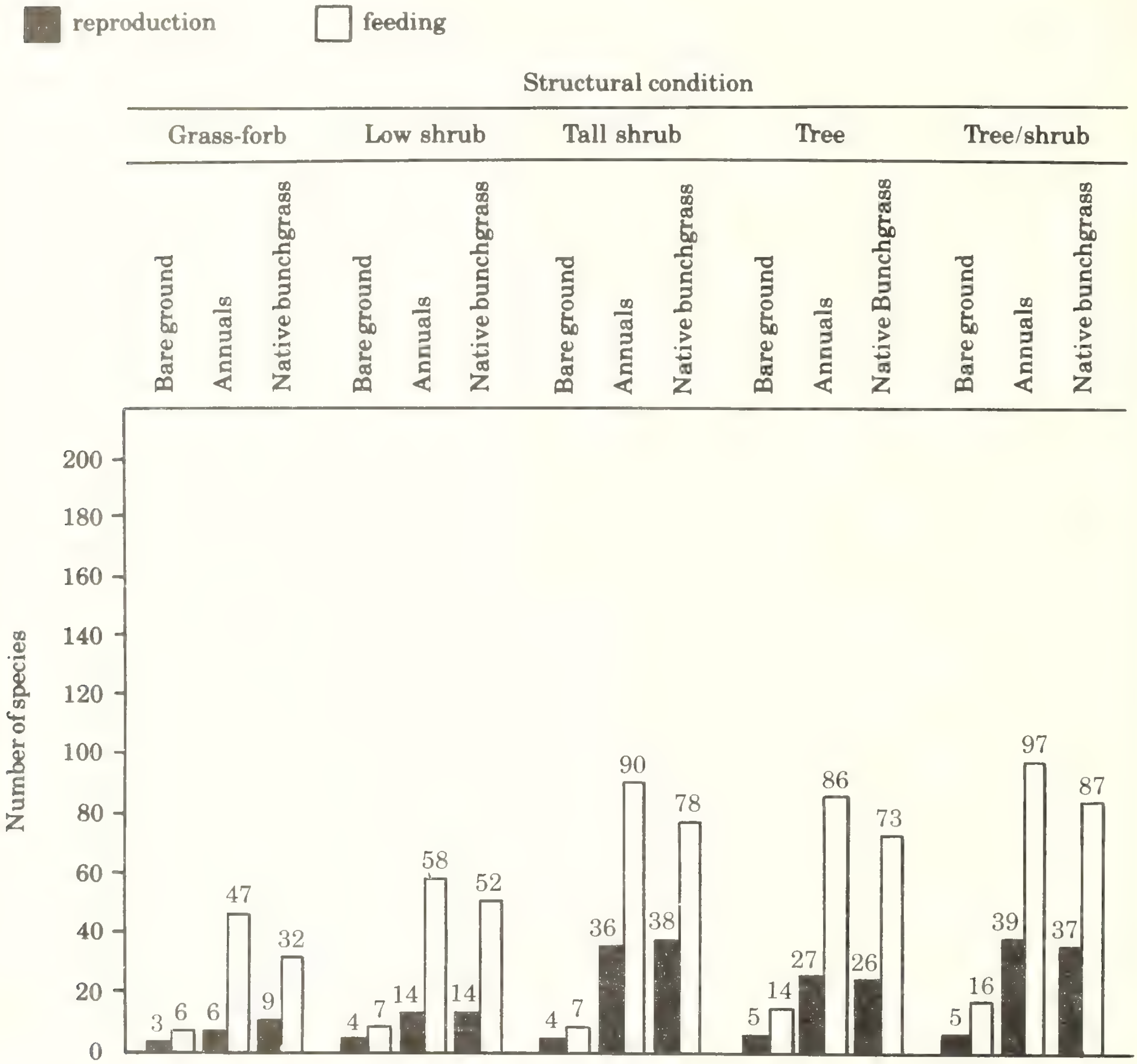
Plant community: Curlleaf mountainmahogany/pinegrass



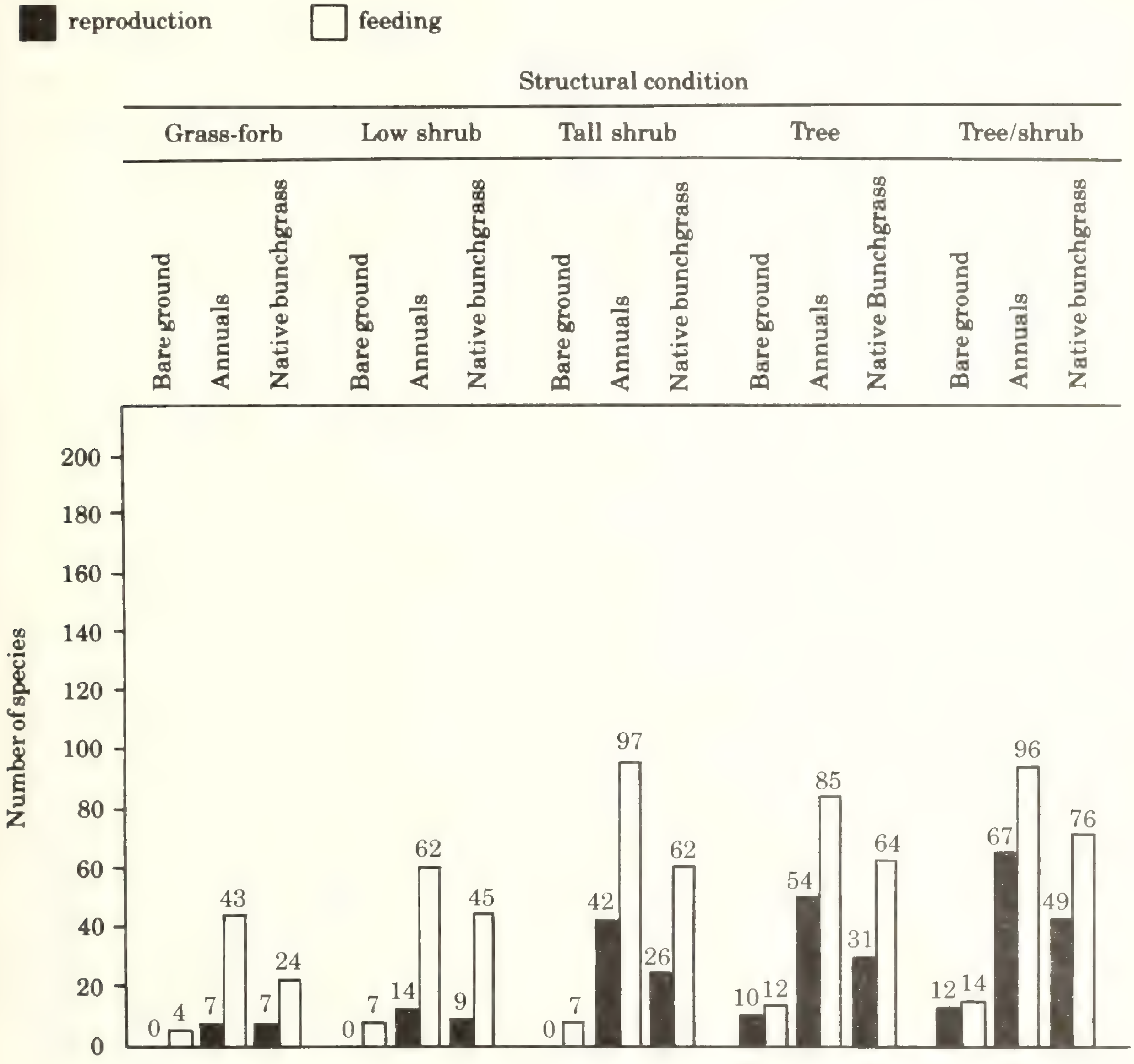
Plant community: Juniper/sagebrush/bunchgrass



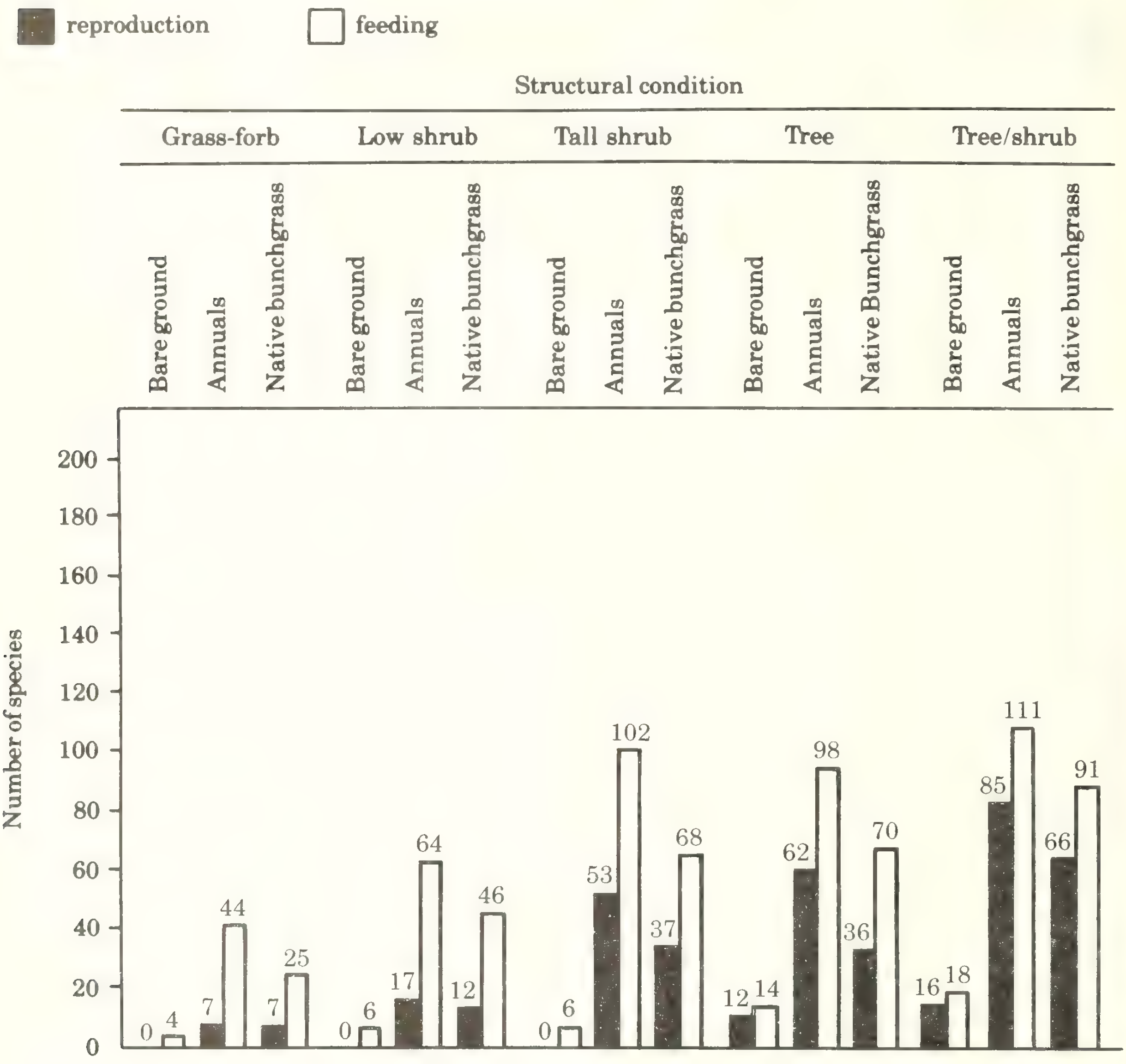
Plant community: Curlleaf mountainmahogany/shrub



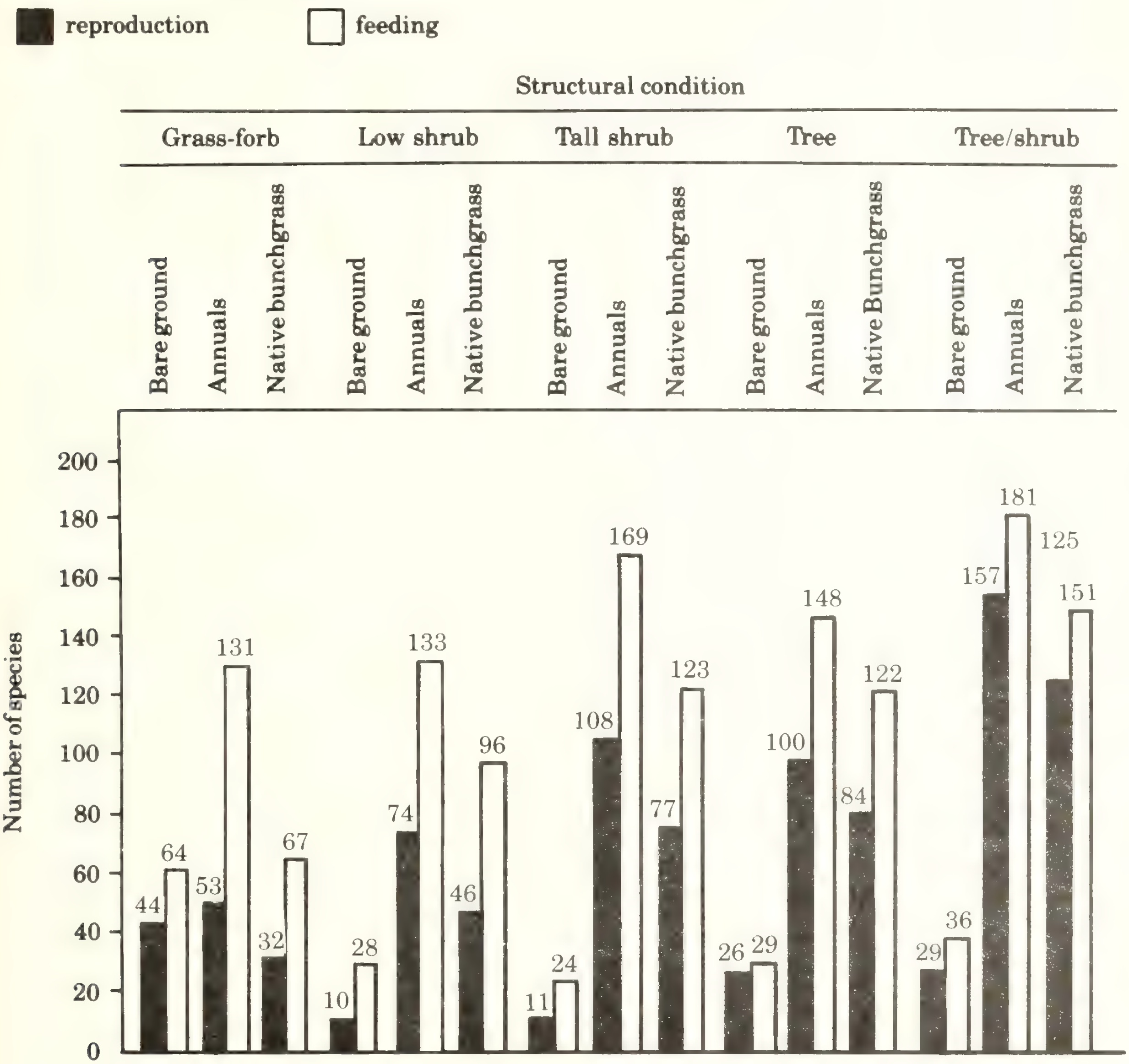
Plant community: Quaking aspen/grass



Plant community: Quaking aspen/mountain big sagebrush/bunchgrass



Plant community: Riparian



Appendix 10. Species-specific references used to construct appendix 1 (selected representative references).

Common name	Scientific name	References
AMPHIBIANS		
ORDER CAUDATA		Stebbins 1951, 1966
Family Ambystomidae		
long-toed salamander	*Ambystoma macrodactylum*	Anderson 1967, 1968, Farner and Kezer 1955
ORDER ANURA		
Family Pelobatidae		
Great Basin spadefoot	*Scaphiopus intermontanus*	Bragg 1945, Mayhew 1965, Pearson 1955, 1957, Wasserman 1958
Family Bufonidae		
western toad	*Bufo boreas*	Campbell 1970, Clarke 1974b, Lillywhite et al. 1973
Woodhouse toad	*Bufo woodhousei*	Bragg 1940, Clarke 1974a, Thornton 1960
Family Hylidae		
Pacific tree frog	*Hyla regilla*	Brown 1975, Jameson 1956, Jameson et al. 1970
Family Ranidae		
spotted frog	*Rana pretiosa*	Hollenbeck 1974, Licht 1975, Morris and Tanner 1969, Turner 1960
leopard frog	*Rana pipiens*	Hine et al. 1975, Pace 1974, Ruibal 1962
bullfrog	*Rana catesbeiana*	Darham and Bennett 1963, Sebetich 1969, Wiewandt 1969
REPTILES		
ORDER SQUAMATA		Ditmars 1936, Schmidt and Davis 1941, Stebbins 1954, 1966, Storm and Pimentel 1949, Tanner and Banta 1966, Wright and Wright 1957
Family Iguanidae		Pianka and Parker 1975
collared lizard	*Crotaphytus collaris*	Fitch 1956, Storm 1966, Talley 1974
leopard lizard	*Crotaphytus wislizeni*	Parker and Pianka 1976, Tanner and Krogh 1974

Common name	Scientific name	References
western fence lizard	*Sceloporus occidentalis*	Davis and Verbeek 1972, Goldberg 1973, 1974, 1975, Jameson and Allison 1976, Marcellini and Mackey 1970, Rose 1976
sagebrush lizard	*Sceloporus graciosus*	Derickson 1976, Stebbins and Robinson 1946, Tinkle 1973, Woodbury and Woodbury 1945
side-blotched lizard	*Uta stansburiana*	Nussbaum and Diller 1976, Parker 1974a, Parker and Pianka 1975, Tinkle 1967
desert horned lizard	*Phrynosoma platyrhinos*	Clark and Comanor 1976, Pianka and Parker 1975, Tanner and Krogh 1973
short-horned lizard	*Phrynosoma douglassi*	Goldberg 1971, Heath 1965, Knowlton and Baldwin 1953, Reeve 1952
Family Scinicidae		
western skink	*Eumeces skiltonianus*	Maser n.d., Tanner 1943, 1957
Family Teiidae		
western whiptail	*Cnemidophorus tigris*	Apslund 1974, Burkholder and Walker 1973, Parker 1972, Pianka 1970, Vitt and Ohmart 1977
Family Boidae		Schmidt and Davis 1941
rubber boa	*Charina bottae*	Peabody et al. 1975
Family Colubridae		Parker 1974b
yellow-bellied racer	*Coluber constrictor*	Brown and Parker 1976, Fitch 1963, Herzog and Burghardt 1974
striped whipsnake	*Masticophis taeniatus*	Parker 1974b, 1976, Parker and Brown 1972
gopher snake	*Pituophis melanoleucus*	Bogert and Roth 1966, Goldberg and Parker 1975, Greenwald 1974, Parker 1974b, Stull 1940
common garter snake	*Thamnophis sirtalis*	Aleksiuk 1977, Carpenter 1952, Fitch 1965
wandering garter snake	*Thamnophis elegans*	Fox 1948, 1951, Gregory 1978
western ground snake	*Sonora semiannulata*	Staedeli 1964, Stickel 1943, Storm 1947, Talley n.d.
night snake	*Hypsiglena torquata*	Clark and Lieb 1973

Common name	Scientific name	References
Family Viperidae		
Western rattlesnake	*Crotalus viridis*	Klauber 1972, Parker and Brown 1974, Rahn 1942
BIRDS		General – American Ornithologists' Union 1957, 1973a, 1973b, 1976, Bent 1926, 1961a, 1961b, 1962a, 1962b, 1962c, 1962d, 1963a, 1963b, 1963c, 1963d, 1963e, 1964a, 1964b, 1964c, 1964d, 1964e, 1964f, 1964g, 1965a, 1965b, 1968a, 1968b, 1968c, Bertrand and Scott 1973, Craighead and Craighead 1969, Flack 1976, Gabrielson and Jewett 1970, Gashwiler 1977, Jackman and Scott 1975, Olendorff and Stoddart 1974, Peterson 1961, Preston and Norris 1947, Reeves 1975
ORDER GAVIIFORMES		
Family Gaviidae		Scott et al. 1972
common loon	*Gavia immer*	McIntyre 1975, 1978, Olson and Marshall 1952
ORDER PODICIPEDIFORMES		
Family Podicipedidae		
red-necked grebe	*Podiceps grisegena*	Kebbe 1958, Kiss and Sterbetz 1973, Spahn 1978
horned grebe	*Podiceps auritus*	Faaborg 1976, Fjeldsa 1973a, 1973b, Sugden 1977
eared grebe	*Podiceps nigricollis*	Faaborg 1976, McAllister 1955, 1964, Storer et al. 1976
western grebe	*Aechmophorus occidentalis*	Feerer and Garrett 1977, Lawrence 1950, Lindvall 1976, Nuechterlein 1975
pied billed grebe	*Podilymbus podiceps*	Faaborg 1976, Glover 1953, Kirby 1976, Sealy 1978a
ORDER PELECANIFORMES		
Family Pelecanidae		
American white pelican	*Pelecanus erythrorhynchos*	Johnson and Sloan 1978, Knopf 1975, Sloan 1973

Common name	Scientific name	References
Family Phalacrocoracidae		
double-crested cormorant	*Phalacrocorax auritus*	Ellison and Cleary 1978, Lack 1945, Van Tets 1959
ORDER CICONIIFORMES		
Family Ardeidae		
great blue heron	*Ardea herodias*	Henny and Bethers 1971, Krebs 1974, Meyerrieks 1960, Nehls 1972
green heron	*Butorides striatus*	Kushlan 1976
common egret	*Casmerodius albus*	Jenni 1969, Pratt 1970
cattle egret	*Bubulcus ibis*	Blaker 1969, Burger 1978, Curry-Lindahl 1971
black-crowned night heron	*Nycticorax nycticorax*	Allen and Mangels 1938-39, Hoffman and Prince 1975, Nickell 1966, Wolford and Boag 1971
American bittern	*Botaurus lentiginosus*	Duebbert and Lokemoen 1977
least bittern	*Ixobrychus exilis*	Weller 1961
Family Threskiornithidae		
white-faced ibis	*Plegadis chihi*	Burger and Miller 1977, Ryder 1967b
ORDER ANSERIFORMES		Bellrose 1976
Family Anatidae		
whistling swan	*Olor columbianus*	Scott 1977, Sherwood 1960
Canada goose	*Branta canadensis*	Cooper 1978, Jarvis and Harris 1967, Martin 1964
white-fronted goose	*Anser albiforns*	Mickelson 1975
snow goose	*Chen caerulescens*	Cooch 1958, Dzubin and Stephen 1975, Kerbes 1975
Ross' goose	*Chen rossii*	Barry 1964, Ryder 1967a, 1972
mallard	*Anas platyrhynchos*	Anderson and Henny 1972, Anderson et al. 1974, Martin and Carney 1977, Pospahala et al. 1974
gadwall	*Anas strepera*	Gates 1962, Jensen 1949, Serie and Swanson 1976
common pintail	*Anas acuta*	Fuller 1953, Krapu 1977, Rundquist 1973, Smith 1970

Common name	Scientific name	References
green-winged teal	*Anas crecca*	Bennett and Bolen 1978, Moisan 1966
blue-winged teal	*Anas discors*	Swanson and Meyer 1977, Swanson et al. 1974, Wheeler 1965
cinnamon teal	*Anas cyanoptera*	Connelly 1978, Spencer 1953
American wigeon	*Anas americana*	Gates 1958, 1962
northern shoveler	*Anas clypeata*	Girard 1939, March 1967, Poston 1974
wood duck	*Aix sponsa*	Gilmer et al. 1978, McGilvrey 1968, Wildl. Manage. Inst. 1966
redhead	*Aythya americana*	McKnight 1974, Michot 1976, Weller 1964
ring-necked duck	*Aythya collaris*	Marshall and Duebbert 1965, Mendall 1958
canvasback	*Aythya valisineria*	Erickson 1948, Hochbaum 1944, Olson 1964, Sugden 1978
greater scaup	*Aythya marila*	Gehrman 1951
lesser scaup	*Aythya affinis*	Bartonek and Hickey 1969, Himes 1977, Rogers 1962
common goldeneye	*Bucephala clangula*	Gibbs 1961, McLaren 1962,
Barrow's goldeneye	*Bucephala islandica*	Griffee 1958, Myres 1957
bufflehead	*Bucephala albeola*	Erskine 1960, 1961, Griffee 1961a, Munro 1942
King eider	*Somateria spectabilis*	
oldsquaw	*Clangula hyemalis*	Ellarson 1956, Rofritz 1977
ruddy duck	*Oxyura jamaicensis*	McKnight 1974, Misterek 1974,Siegfried 1977
hooded merganser	*Lophodytes cucullatus*	Griffee 1954, Kitchen 1968, Morse et al. 1969
common merganser	*Mergus merganser*	Erskine 1972, Miller and Barclay 1974
red-breasted merganser	*Mergus serrator*	Lingle and Schupbach 1977
ORDER FALCONIFORMES		Brown and Amadon 1968, Craighead and Craighead 1969
Family Cathartidae		
turkey vulture	*Cathartes aura*	Coles 1938, Jackson et al. 1978, Stewart 1977

Common name	Scientific name	References
Family Accipitridae		
northern goshawk	*Accipiter gentilis*	Reynolds 1978, Reynolds and Wight 1978
sharp-shinned hawk	*Accipiter striatus*	Brown 1973, Platt 1973
Cooper's hawk	*Accipiter cooperii*	Henny and Wight 1972, Meng 1952
red-tailed hawk	*Buteo jamaicensis*	Fitch et al. 1946, Gates 1972, Luttich et al. 1970
Swainson's hawk	*Buteo swainsoni*	Dunkle 1977, Fitzner 1978, Olendorff 1972
rough-legged hawk	*Buteo lagopus*	Schnell 1968, Springer 1975
ferruginous hawk	*Buteo regalis*	Wakeley 1974, Weston 1969, Woffinden 1975, Woffinden and Murphy 1977
golden eagle	*Aquila chrysaetos*	Beecham and Kochert 1975, McGahan 1968, Mosher and White 1976, Murphy et al. 1969, Seibert et al. 1976, Snow 1973c
bald eagle	*Haliaeetus leucocephalus*	Mathisen et al. 1977, Murphy 1977, Platt 1976, Snow 1973b, Steenhoff 1978
northern harrier	*Circus cyaneus*	Clark and Ward 1974, Duebbert and Lokemoen 1977, Hamerstrom 1969
Family Pandionidae		
osprey	*Pandion haliaetus*	Henny 1977, Henny et al. 1978, Melquist et al. 1978, Zarn 1974b
Family Falconidae		
prairie falcon	*Falco mexicanus*	Denton 1976, Ogden and Hornocker 1977, Parker 1973, Snow 1974b
peregrine	*Falco peregrinus*	Hickey 1969, Porter and White 1973, Snow 1972
merlin	*Falco columbarius*	Fox 1971, Hodson 1976, Trimble 1975a
American kestrel	*Falco sparverius*	Enderson 1960, Henny et al. 1976, Smith et al. 1972

Common name	Scientific name	References
ORDER GALLIFORMES		
Family Tetraonidae		
blue grouse	*Dendragapus obscurus*	Bendell and Elliott 1967, Donaldson and Bergerud 1974, Severson 1978, Weber et al. 1974
ruffed grouse	*Bonasa umbellus*	Bump et al. 1947, Moulton and Vanderschaegen 1974, Robertson 1976
sage grouse	*Centrocercus urophasianus*	Braun et al. 1977, Gray 1967, Wallestad 1975
Family Phasianidae		
California quail	*Lophortyx californicus*	Anthony 1970, Storer et al. 1942, Sumner 1935
mountain quail	*Oreortyx pictus*	Gutierrez 1975, Lahnum 1944, Ormiston 1966
chukar	*Alectoris chukar*	Galbreath and Moreland 1953, Mackie and Buechner 1963, Molini 1976
gray partridge	*Perdix perdix*	McKinney 1966, Weigand 1977, Westerskov 1949
ring-necked pheasant	*Phasianus colchicus*	Allen 1956, Crouse 1941, Olsen 1977
ORDER GRUIFORMES		
Family Gruidae		
sandhill crane	*Grus canadensis*	Drewien and Bizeau 1974, Mullins and Bizeau 1978, Walkinshaw 1949
Family Rallidae		
Virginia rail	*Rallus limicola*	Billard 1947, Glahn 1974, Horak 1964, Reeves 1975
sora	*Porzana carolina*	see Virginia rail
American coot	*Fulica americana*	Crawford 1977, Frederickson 1970, Jahn 1965, Jones 1940
ORDER CHARADRIIFORMES		Stout 1967
Family Charadriidae		Gerstenberg and Jurek 1972
semi-palmated plover	*Charadrius semipalmatus*	

Common name	Scientific name	References
snowy plover	*Charadrius alexandrinus*	Oreg. Dep. Fish & Wildl. 1977, Purdue 1974
killdeer	*Charadrius vociferus*	Bunni 1959, Lenington and Mace 1975, Mace 1978
mountain plover	*Charadrius montanus*	Graul 1975, Laun 1957
Family Scolopacidae		Gerstenberg and Jurek 1972
common snipe	*Capella gallinago*	Reeves 1975, Tuck 1972, Winegardner 1976
long-billed curlew	*Numeninus americanus*	Bicak 1977, Bucher 1978, McCallum et al. 1977, Sadler and Maher 1976
spotted sandpiper	*Actitis macularia*	Nelson 1939
solitary sandpiper	*Tringa solitaria*	
greater yellowlegs	*Tringa melanoleuca*	
lesser yellowlegs	*Tringa flavipes*	
willet	*Catoptrophorus semipalmatus*	
pectoral sandpiper	*Calidris melanotos*	Pitelka 1959
Baird's sandpiper	*Calidris bairdii*	
least sandpiper	*Calidris minutilla*	
western sandpiper	*Calidris mauri*	
long-billed dowitcher	*Limnodromus scolopaceus*	
marbled godwit	*Limosa fedoa*	
Family Recurvirostridae		Gerstenberg and Jurek 1972, Wetmore 1925
American avocet	*Recurvirostra americana*	Bucher 1978, Gibson 1971
black-necked stilt	*Himantopus mexicanus*	
Family Phalaropodidae		Wetmore 1925
Wilson's phalarope	*Steganopus tricolor*	Burger and Howe 1975, Höhn 1967, Johns 1969
northern phalarope	*Lobipes lobatus*	Cole 1943, Hohn 1971, Tinbergen 1935
Family Laridae		
herring gull	*Larus argentatus*	Hunt 1972
California gull	*Larus californicus*	Greenhalgh 1952, Vermeer 1970

Common name	Scientific name	References
ring-billed gull	*Larus delawarensis*	Broadbooks 1961, Miller and Emlen 1975, Vermeer 1970
Franklin's gull	*Larus pipixcan*	Burger 1974, Jewett 1949
Bonaparte's gull	*Larus philadelphia*	
Forster's tern	*Sterna forsteri*	McNicholl 1971, Salt and Willard 1971, Storey 1977
Caspian tern	*Sterna caspia*	
black tern	*Chlidonias niger*	Einarsen 1941
ORDER COLUMBIFORMES		
Family Columbidae		
rock dove	*Columba livia*	Kindschy 1964, Murton et al. 1972, 1974
mourning dove	*Zenaida macroura*	Dolton 1977, Miles 1976, Ruos and Dolton 1977, U.S. Fish and Wildl. Serv. 1962
ORDER CUCULIFORMES		
Family Cuculidae		
yellow-billed cuckoo	*Coccyzus americanus*	Quaintance 1944
ORDER STRIGIFORMES		Burton 1973, Craighead and Craighead 1969
Family Tytonidae		
barn owl	*Tyto alba*	Henny 1969, Rudolph 1978 Smith and Marti 1976, Smith et al. 1974, Stewart 1952
Family Strigidae		
common screech owl	*Otus asio*	Nowicki 1974, Smith and Wilson 1971, VanCamp and Henny 1975
flammulated owl	*Otus flammeolus*	Balda et al. 1975, Marshall 1939, Winter 1974
great horned owl	*Bubo virginianus*	Baumgartner 1939, Rusch et al. 1972, Stewart 1969
pygmy owl	*Glaucidium gnoma*	Burton 1973
burrowing owl	*Athene cunicularia*	Collins and Landry 1977, Maser et al. 1971, Zarn 1974a
long-eared owl	*Asio otus*	Glue 1977, Maser et al. 1970, Sonnenberg and Powers 1976

Common name	Scientific name	References
short-eared owl	*Asio flammeus*	Banfield 1947, Clark 1975, Marti 1974
Saw-whet owl	*Aegolius acadicus*	Forbes and Warner 1974, Kebbe 1959, Woods 1972
ORDER CAPRIMULGIFORMES		Trimble 1975b
Family Caprimulgidae		
poorwill	*Phalaenoptilus nuttallii*	Horn and Marshall 1975
common nighthawk	*Chordeiles minor*	Armstrong 1965, Dexter 1961, Rust 1947, Selander 1954
ORDER APODIFORMES		Trimble 1975b
Family Apodidae		
black swift	*Cypseloides niger*	
Vaux's swift	*Chaetura vauxi*	Baldwin and Hunter 1963, Baldwin and Zaczkowski 1963, Griffee 1961b, Thompson 1977
white-throated swift	*Aeronautes saxatalis*	Weber 1975
Family Trochilidae		Greenwalt 1960
black-chinned hummingbird	*Archilochus alexandri*	
broad-tailed hummingbird	*Selasphorus platycercus*	Calder 1973, Calder and Booser 1973, Lyon 1973
rufous hummingbird	*Selasphorus rufus*	Gass et al. 1976, Horvath 1964
calliope hummingbird	*Stellula calliope*	Calder 1971, 1973
Anna's hummingbird	*Calypte anna*	Pitelka 1951a, Stiles 1971, Stiles and Wolf 1973
ORDER CORACIIFORMES		
Family Alcedinidae		Trimble 1975b
belted kingfisher	*Megaceryle alcyon*	Hamas 1974, Kilham 1974
ORDER PICIFORMES		Williams 1975, Williams and Batzli 1979
Family Picidae		Conner 1973, Conner et al. 1975, 1976, Jackman 1974
common flicker	*Colaptes auratus*	Anderson 1972, Conner 1973
yellow-bellied sapsucker	*Sphyrapicus varius*	Erskine and McLaren 1972, Kilham 1971a, Lawrence 1967
Williamson's sapsucker	*Sphyrapicus thyroideus*	Crockett and Hansley 1977, Michael 1936

Common name	Scientific name	References
Lewis' woodpecker	*Picoides lewis*	Bock 1970, Bock et al. 1971
hairy woodpecker	*Picoides villosus*	Kilham 1968a, Lawrence 1967, Staebler 1949
downy woodpecker	*Picoides pubescens*	Jackson 1970, Lawrence 1967, Staebler 1949
white-headed woodpecker	*Picoides albolarvatus*	Ligon 1973
ORDER PASSERIFORMES		Verner and Willson 1969
Family Tyrannidae		Trimble 1975b
eastern kingbird	*Tyrannus tyrannus*	Dick and Rising 1965, Hespenheide 1964, Morehouse and Brewer 1968
western kingbird	*Tyrannus verticalis*	Dick and Rising 1965, Ohlendorf 1974
ash-throated flycatcher	*Myiarchus cinerascens*	
Say's phoebe	*Sayornis saya*	Ohlendorf 1976, Whitaker 1974
Genus *Empidonax*		Ashmole 1968
willow flycatcher	*Empidonax traillii*	Aldrich 1955, King 1955, Robbins 1974
Hammond's flycatcher	*Empidonax hammondii*	Beaver and Baldwin 1975, Davis 1954, Manuwal 1970
gray flycatcher	*Empidonax wrightii*	Johnson 1963, Lavers 1975, Russell and Woodbury 1941
western flycatcher	*Empidonax difficilis*	Brodkorb 1949, Davis et al. 1963
western wood pewee	*Contopus sordidulus*	
olive-sided flycatcher	*Nuttallornis borealis*	
Family Alaudidae		
horned lark	*Eremophila alpestris*	Beason and Franks 1974, Pickwell 1931, Verbeek 1967
Family Hirundinidae		Trimble 1975b
violet-green swallow	*Tachycineta thalassina*	Combellack 1954
tree swallow	*Iridoprocne bicolor*	Chapman 1935, Kuerzi 1940-41
bank swallow	*Riparia riparia*	Freer 1977, Petersen 1955, Stoner 1936
rough-winged swallow	*Stelgidopteryx ruficollis*	Lunk 1962

Common name	Scientific name	References
barn swallow	*Hirundo rustica*	Henny 1972, Jackson and Burchfield 1975, Mason 1953
cliff swallow	*Petrochelidon pyrrhonota*	Buss 1942, Emlen 1952, Mayhew 1958
Family Corvidae		Jollie 1976, Trimble 1975b, Turcek and Kelso 1968
gray jay	*Perisoreus canadensis*	Aldrich 1943, Ouellet 1970, Rutter 1969
Steller's jay	*Cyanocitta stelleri*	Brown 1963
scrub jay	*Aphelocoma coerulescens*	Pitelka 1951b
black-billed magpie	*Pica pica*	Bock and Lepthien 1975, Brown 1957, Erpino 1968, Jones 1960
northern raven	*Corvus corax*	Larsen and Dietrich 1970, Maser 1975, Montevecchi 1978, Stiehl 1978
American crow	*Corvus brachyrhynchos*	Good 1952, Montevecchi 1976, Platt 1956
pinyon jay	*Gymnorhinus cyanocephalus*	Balda and Bateman 1971, Bateman and Balda 1973, Ligon and Martin 1974
Clark's nutcracker	*Nucifraga columbiana*	Giuntoli and Mewaldt 1978, Mewaldt 1956, Tomback 1977
Family Paridae		Trimble 1975b
black-capped chickadee	*Parus atricapillus*	Henny 1972, Kessel 1976, Odum 1941a, 1941b, Sturman 1968
mountain chickadee	*Parus gambeli*	Dixon 1961, Kluyver 1961
bushtit	*Psaltriparus minimus*	Ervin 1977
Family Sittidae		
white-breasted nuthatch	*Sitta carolinensis*	Kilham 1968b, 1971a, 1971b, 1972
red-breasted nuthatch	*Sitta canadensis*	Anderson 1976a, Kilham 1973, Stallcup 1968
Family Certhiidae		
brown creeper	*Certhia familiaris*	Apfelbaum and Haney 1977, McClelland 1975, McClelland and Frissell 1975
Family Cinclidae		
dipper	*Cinclus mexicanus*	Parsons 1975, Price and Bock 1973, Thut 1970

Common name	Scientific name	References
Family Troglodytidae		Trimble 1975b
house wren	*Troglodytes aedon*	Kendeigh 1941, Kroodsma 1973
winter wren	*Troglodytes troglodytes*	Armstrong 1956, Evenden 1950
marsh wren	*Cistothorus palustris*	Kale 1965, Verner 1963, 1975, Verner and Engelsen 1970
canyon wren	*Catherpes mexicanus*	Grinnell and Behle 1935
rock wren	*Salpinctes obsoletus*	Knowlton and Harmston 1942, Kroodsma 1975
Family Mimidae		Trimble 1975b
gray catbird	*Dumetella carolinensis*	Fletcher and Smith 1978, Harcus 1973
brown thrasher	*Toxostoma rufum*	
sage thrasher	*Oreoscoptes montanus*	Reynolds and Rich 1978, Rich 1978b
Family Turdidae		Trimble 1975b
American robin	*Turdus migratorius*	Farner 1949, Henny 1972, James and Shugart 1974
varied thrush	*Ixoreus naevius*	Martin 1970a
hermit thrush	*Catharus guttatus*	Cochran et al. 1967, Morse 1972, Noon 1977
Swainson's thrush	*Catharus ustulatus*	Morse 1972, Noon 1977
veery	*Catharus fuscescens*	Aldrich 1939, Bertin 1977, Noon 1977
western bluebird	*Sialia mexicana*	Herlugson 1978, Pinkowski 1978, Pinkowski and Zeleny 1975
mountain bluebird	*Sialia currucoides*	Haecker 1948, Pinkowski 1978, Pinkowski and Zeleny 1975, Power 1966
Townsend's solitaire	*Myadestes townsendi*	Lederer 1977a, 1977b, Solomonson and Balda 1977
Family Sylviidae		Trimble 1975b
blue-gray gnatchatcher	*Polioptila caerulea*	
ruby-crowned kinglet	*Regulus calendula*	
Family Motacillidae		
water pipit	*Anthus spinoletta*	Gibb 1956, Verbeek 1970

Common name	Scientific name	References
Family Bombycillidae		
bohemian waxwing	*Bombycilla garrulus*	Bakke 1977, Knapton and Sexton 1978
cedar waxwing	*Bombycilla cedrorum*	Burleigh 1963, Gollob and Pulich 1978
Family Laniidae		
northern shrike	*Lanius excubitor*	Cade 1962, 1967, Davis 1974
loggerhead shrike	*Lanius ludovicianus*	Craig 1978, Porter et al. 1975, Smith 1973a, 1973b
Family Sturnidae		
European starling	*Sturnus vulgaris*	Bray et al. 1975, DeHaven and DeHaven 1973, Planck 1967
Family Vireonidae		Chapin 1925, Trimble 1975b
solitary vireo	*Vireo solitarius*	Hamilton 1962, James 1973, 1976
red-eyed vireo	*Vireo olivaceus*	Lawrence 1953, Southern 1958, Williamson 1971
warbling vireo	*Vireo gilvus*	James 1976
Family Parulidae		Griscom and Sprunt 1957, Trimble 1975b
orange-crowned warbler	*Vermivora celata*	Ficken and Ficken 1962a
Nashville warbler	*Vermivora ruficapilla*	Lawrence 1948, Roth 1977
yellow warbler	*Dendroica petechia*	Ficken and Ficken 1965, Morse 1973
yellow-rumped warbler	*Dendroica coronata*	Hubbard 1969
black-throated gray warbler	*Dendroica nigrescens*	
Townsend's warbler	*Dendroica townsendi*	
ovenbird	*Seiurus aurocapillus*	Littlefield and McLaury 1975, Stenger 1958, Zach and Falls 1979
MacGillivray's warbler	*Oporornis tolmiei*	
common yellowthroat	*Geothlypis trichas*	Hofslund 1959, Wunderle 1978
yellow-breasted chat	*Icteria virens*	Ficken and Ficken 1962b, Stewart 1953, Thompson and Nolan 1973
Wilson's warbler	*Wilsonia pusilla*	Stewart et al. 1977
American redstart	*Setophaga ruticilla*	Ficken and Ficken 1967, McLaren 1975, Morse 1973

Common name	Scientific name	References
Family Ploceidae		
house sparrow	*Passer domesticus*	Kendeigh 1973, Summers-Smith 1967, 1968
Family Icteridae		Crase and DeHaven 1975, Trimble 1975b
bobolink	*Dolichonyx oryzivorus*	Martin 1970b, 1974
western meadowlark	*Sturnella neglecta*	Anderson and Merrill 1967, Knowlton and Maddock 1943, Lanyon 1957
yellow-headed blackbird	*Xanthocephalus xanthocephalus*	Lederer 1978, Willson 1966, Willson and Orians 1963
red-winged blackbird	*Agelaius phoeniceus*	Cutright 1973, Dolbeer 1978, Krapu 1978, Robertson 1972
northern oriole	*Icterus galbula*	Pleasants 1977, 1979, Schaefer 1976
Brewer's blackbird	*Euphagus cyanocephalus*	Hansen and Carter 1963, Horn 1968, Stepney 1975, Williams 1952
brown-headed cowbird	*Molothrus ater*	Friedmann 1963, Hill 1976, Payne 1976
Family Thraupidae		Trimble 1975b
western tanager	*Piranga ludoviciana*	
Family Fringillidae		Trimble 1975b
rose-breasted grosbeak	*Pheucticus ludovicianus*	Kroodsma 1974, Lemon and Chatfield 1973
black-headed grosbeak	*Pheucticus melanocephalus*	Kroodsma 1974
indigo bunting	*Passerina cyanea*	Emlen et al. 1975, Wells 1958, Whitmore 1975
lazuli bunting	*Passerina amoena*	Emlen et al. 1975, Thompson 1976, Whitmore 1975
evening grosbeak	*Hesperiphona vespertina*	Balph and Balph 1976, Blais and Parks 1964, Dexter 1975
purple finch	*Carpodacus purpureus*	Pulliam and Enders 1971
Cassin's finch	*Carpodacus cassinii*	Balph 1978, Herman 1971, Samson 1976
house finch	*Carpodacus mexicanus*	Thompson 1960
common redpoll	*Carduelis flammea*	Evans 1969, Kennard 1976, Pohl and West 1976, 1978

Common name	Scientific name	References
pine siskin	*Carduelis pinus*	Eriksson 1970, Harris 1975
American goldfinch	*Carduelis tristis*	Holcomb 1969, Miller 1978, Nickell 1951
lesser goldfinch	*Carduelis psaltria*	
green-tailed towhee	*Pipilo chlorura*	
rufous-sided towhee	*Pipilo erythrophthalmus*	Baumann 1959, Davis 1960, Greenlaw 1978
savannah sparrow	*Passerculus sandwichensis*	Bradley 1973, Dixon 1978, Welsh 1975, Wiens 1973
grasshopper sparrow	*Ammodramus savannarum*	Pulliam and Mills 1977, Smith 1963, Wiens 1973
vesper sparrow	*Pooecetes gramineus*	Best 1972, Pulliam and Mills 1977, Simpson 1978
lark sparrow	*Chondestes grammacus*	Renwald 1977
sage sparrow	*Amphispiza belli*	Braun et al. 1976, Moldenhauer 1970, Moldenhauer and Wiens 1970, Rich 1978a
northern junco	*Junco hyemalis*	Balph 1977, Gottfried and Franks 1975, Sabine 1959
American tree sparrow	*Spizella arborea*	Anderson 1973, Heydweiller 1935, Stenger 1965, Weeden 1965
chipping sparrow	*Spizella passerina*	Hebrand 1974, Klopfer 1965, Pulliam and Mills 1977
Brewer's sparrow	*Spizella breweri*	Best 1972, Rich 1978a
white-crowned sparrow	*Zonotrichia leucophrys*	Cortopassi and Mewaldt 1965, Lewis 1975, Morton et al. 1972, Rees 1973
golden-crowned sparrow	*Zonotrichia atricapilla*	Balph 1976
fox sparrow	*Passerella iliaca*	Banks 1970
Lincoln's sparrow	*Melospiza lincolnii*	Miller 1939, Miller and McCabe 1935
song sparrow	*Melospiza melodia*	Knapton and Krebs 1974, Nice 1943, Tompa 1962
Lapland longspur	*Calcarius lapponicus*	
snow bunting	*Plectrophenax nivalis*	Nethersole-Thompson 1966, Tinbergen 1939

Common name	Scientific name	References
MAMMALS		General – Bailey 1936, Burt and Grossenheider 1964, Hall and Kelson 1959, Hansen 1956, Harvey 1976, McDaniel and Gardner 1977, McReynolds 1976, Mohr 1976
ORDER INSECTIVORA		
Family Soricidae		
Malheur shrew	*Sorex preblei*	Armstrong 1957, Hoffman and Fisher 1978, Verts 1975
wandering shrew	*Sorex vagrans*	Clothier 1955, Hooven et al. 1975, Ingles 1961, Terry 1978, Whitaker and Maser 1976
Merriam shrew	*Sorex merriami*	Gashwiler 1976, Johnson and Clanton 1954, Lindsay and Perry 1977
ORDER CHIROPTERA		Barbour and Davis 1969, Cross 1977, Saul et al. 1977
Family Vespertilionidae		
little brown myotis	*Myotis lucifugus*	Buchler 1976, Fenton 1970, Kunz et al. 1977, O'Farrell and Studier 1973, 1975
Yuma myotis	*Myotis yumanensis*	Dalquest 1947b
long-eared myotis	*Myotis evotis*	Dalquest 1948
fringed myotis	*Myotis thysanodes*	O'Farrell and Studier 1973, 1975
long-legged myotis	*Myotis volans*	Whitaker et al. 1977
California myotis	*Myotis californicus*	Krutzsch 1954, Whitaker et al. 1977
small-footed myotis	*Myotis leibi*	Fenton 1972, Tuttle and Heaney 1974
silver-haired bat	*Lasionycteris noctivagans*	Sealy 1978b, Whitaker et al. 1977, Whitaker et al. 1981
western pipistrelle	*Pipistrellus hesperus*	Cross 1965, Hoff and Riedesel 1969
big brown bat	*Eptesicus fuscus*	Christian 1956, Davis et al. 1968, Mills et al. 1975

Common name	Scientific name	References
hoary bat	*Lasiurus cinereus*	Constantine 1966, Findley and Jones 1964, Jones 1965, Poche and Bailie 1974, Poche and Ruffner 1975
spotted bat	*Euderma maculata*	Easterla 1971, Snow 1974a, U.S. Dep. Inter. 1973
western big-eared bat	*Plecotus townsendi*	Dalquest 1974a, Graham 1966, Humphrey and Kunz 1976, Pearson et al. 1952
pallid bat	*Antrozous pallidus*	Beck and Rudd 1960, Davis 1969, Orr 1954
ORDER LAGOMORPHA		
Family Leporidae		Hansen 1972
pygmy rabbit	*Sylvilagus idahoensis*	Orr 1940, Severaid 1950
mountain cottontail	*Sylvilagus nuttalli*	Chapman 1975, McKay and Verts 1978, Orr 1940
white-tailed jackrabbit	*Lepus townsendi*	Bear and Hansen 1966, James and Seabloom 1969a, 1969b
black-tailed jackrabbit	*Lepus californicus*	Blackburn 1968, Gross et al. 1974, Haskell and Reynolds 1947
ORDER RODENTIA		
Family Sciuridae		
least chipmunk	*Eutamias minimus*	Meredith 1976, Sheppard 1965, Skryja 1974
yellow-pine chipmunk	*Eutamias amoenus*	Broadbooks 1958, 1970a, 1970b
yellow-bellied marmot	*Marmota flaviventris*	Armitage 1975, Armitage and Downhower 1974, Garrott and Jenni 1978
antelope ground squirrel	*Ammospermophilus leucurus*	Bradley 1967, 1968
Townsend ground squirrel	*Spermophilus townsendi*	Dalquest 1948, Johnson 1977, Shaw 1921
Richardson ground squirrel	*Spermophilus richardsoni*	Michener 1977, Michener and Michener 1977, Zegers 1976
Belding ground squirrel	*Spermophilus beldingi*	Morton and Gallup 1975, Morton et al. 1974, Morton and Sherman 1978, Turner 1972

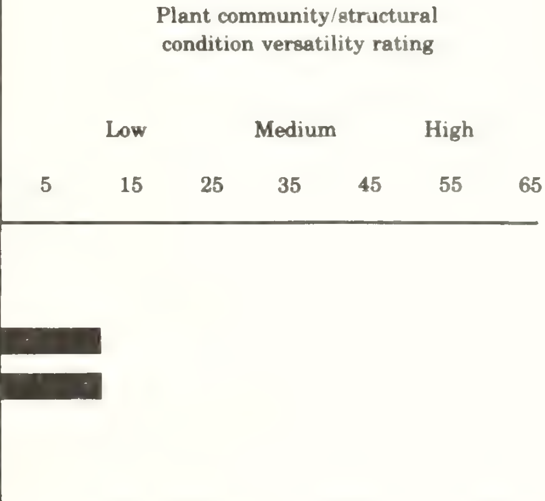
Common name	Scientific name	References
mantled ground squirrel	*Spermophilus lateralis*	Gordon 1943, Tevis 1952 Yousef and Bradley 1971
Family Geomyidae		
Townsend pocket gopher	*Thomomys townsendi*	Hall 1946, Horn 1923
northern pocket gopher	*Thomomys talpoides*	Anderson 1976b, Hansen and Beck 1968, Julander et al. 1969
Family Heteromyidae		
little pocket mouse	*Perognathus longimembris*	
Great Basin pocket mouse	*Perognathus parvus*	Hedlund et al. 1975, Kritzman 1974, O'Farrell et al. 1975, Scheffer 1938
dark kangaroo mouse	*Microdipodops megacephalus*	Ghiselin 1970, O'Farrell and Blaustein 1974
Ord kangaroo rat	*Dipodomys ordi*	Blaustein and Risser 1976, Jorgensen et al. 1980, Lemen and Rosenzweig 1978, Whitford 1976
chisel-toothed kangaroo rat	*Dipodomys microps*	Beatley 1976, Jorgensen 1963, Kenagy 1973
Family Castoride		
beaver	*Castor canadensis*	Ffolliott 1976, Leege 1968, Rutherford 1964
Family Cricetidae		
western harvest mouse	*Reithrodontomys megalotis*	Birkenholz 1967, Fisler 1971, Richens et al. 1974, Whitaker and Mumford 1972
canyon mouse	*Peromyscus crinitus*	Egoscue 1964, Lechleitner 1969
deer mouse	*Peromyscus maniculatus*	Blair 1943, King 1968, Kritzman 1974, Wirtz and Pearson 1960
northern grasshopper mouse	*Onychomys leucogaster*	Egoscue 1960, McCarty 1978, Ruffer 1965
desert woodrat	*Neotoma lepida*	Bleich and Schwartz 1975, Stones and Hayward 1968
bushy-tailed woodrat	*Neotoma cinerea*	Findley 1958, Johnson and Hansen 1979

Common name	Scientific name	References
Family Microtinae		
montane vole	*Microtus montanus*	Murie 1971, Murray 1965, Randall 1978
long-tailed vole	*Microtus longicaudus*	Beck and Anthony 1971, Randall 1978
sage vole	*Lagurus curtatus*	Clanton et al. 1971, Johnson et al. 1948, Maser et al. 1974, Maser and Strickler 1978
muskrat	*Ondatra zibethicus*	Kiviat 1978, Neal 1968, Sather 1958, Willner et al. 1975
Family Zapodidae		
western jumping mouse	*Zapus princeps*	Brown 1967, Cranford 1978, Jones et al. 1978, Stinson 1977
Family Erethizontidae		
porcupine	*Erethizon dorsatum*	Hoven 1971, Smith 1977
Family Canidae		
coyote	*Canis latrans*	Gier 1968, Knowlton 1972, Mathwig 1973
red fox	*Vulpes vulpes*	Sheldon 1949, Stanley 1963, Storm et al. 1976
kit fox	*Vulpes macrotis*	Benedict and Forbes 1979, Egoscue 1962, 1975, Laughrin 1970, Snow 1973a
Family Procyonidae		
raccoon	*Procyon lotor*	Fritzell 1978, Schneider et al. 1971, Urban 1970
Family Mustelidae		Hamilton 1933, Heidt et al. 1976
long-tailed weasel	*Mustela frenata*	Hall 1951
mink	*Mustela vison*	Errington 1943, Northcott et al. 1974, Shump et al. 1976a
badger	*Taxidea taxus*	Lindzey 1978, Sargeant and Warner 1972
spotted skunk	*Spilogale putorius*	Baker and Baker 1975, Crabb 1948, Patton 1974
striped skunk	*Mephitis mephitis*	Bailey 1971, Shump et al. 1975, Verts 1967
river otter	*Lutra canadensis*	Shump et al. 1976b, Tabor and Wight 1977, Toweill 1974

Common name	Scientific name	References
Family Felidae		
cougar	*Felis concolor*	Hornocker 1970, Seidensticker et al. 1973, Sitton 1977
bobcat	*Lynx rufus*	Crowe 1975, Gashwiler et al. 1961, Sweeney 1977
ORDER ARTIODACTYLA		
Family Cervidae		
mule deer	*Odocoileus hemionus*	Dealy 1970
Family Antilocapridae		
pronghorn	*Antilocapra americana*	Autenrieth and Fichter 1975, Kitchen 1974, Sundstrom et al. 1973, Yoakum 1967
Family Bovidae		
bighorn sheep	*Ovis canadensis*	Berger 1978, McGlinchy et al. 1971, Spalding and Mitchell 1970

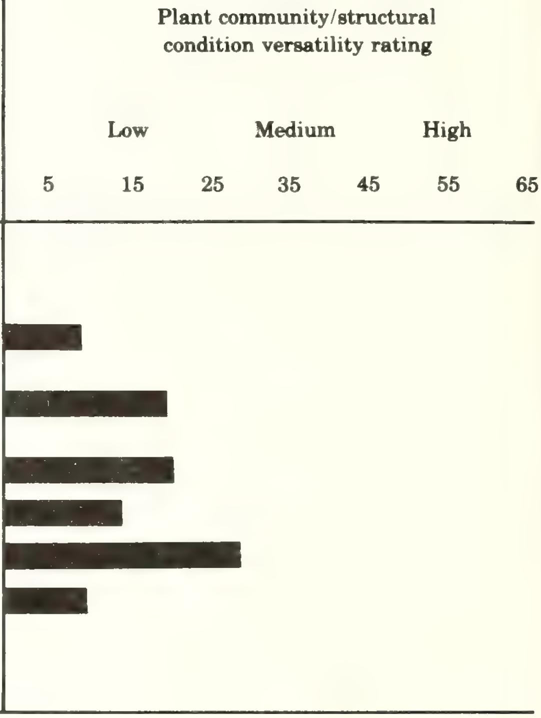
Appendix 11. Species versatility ratings by life form. Life form 1: reproduces in water; feeds in water. (2 species)

Letter code	Species	Reproductive orientation			Feeding orientation			
		No. of plant communities used (1)	No. of structural conditions used (2)	Columns 1 & 2 (3)	No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	AMPHIBIANS							
RAPR	spotted frog	1	5	6	1	5	6	12
RACA	bullfrog	1	5	6	1	5	6	12
							Total	24
							$\overline{X}$ =	12



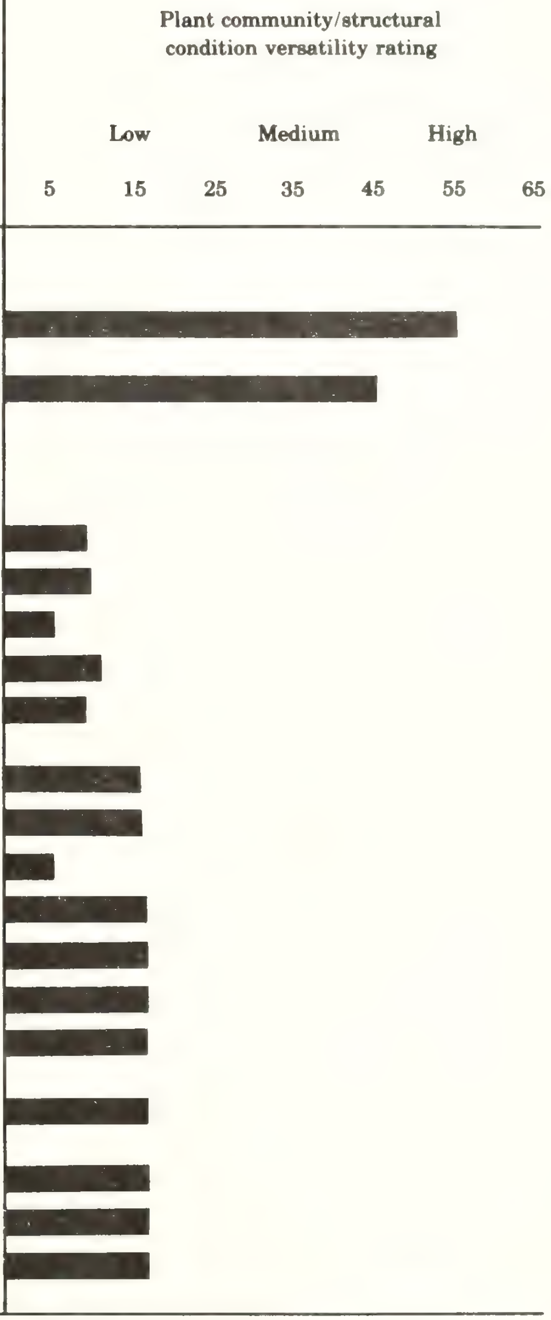
Appendix 11. Life form 2: reproduces in water; feeds on ground, in shrubs, and/or in trees. (6 species)

		Reproductive orientation			Feeding orientation			
Letter code	Species	No. of plant communities used (1)	No. of structural conditions used (2)	Columns 1 & 2 (3)	No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	AMPHIBIANS							
AMMA	long-toed salamander	2	4	6	2	3	5	11
SCIN	Great Basin spadefoot toad	2	4	6	7	10	17	23
BUBO	western toad	2	5	7	8	8	16	23
BUWO	Woodhouse toad	1	4	5	5	6	11	16
HYRE	Pacific treefrog	3	9	12	6	13	19	31
RAPI	leopard frog	1	3	4	1	6	7	11
							Total	115
							$\overline{X}$ =	19.2

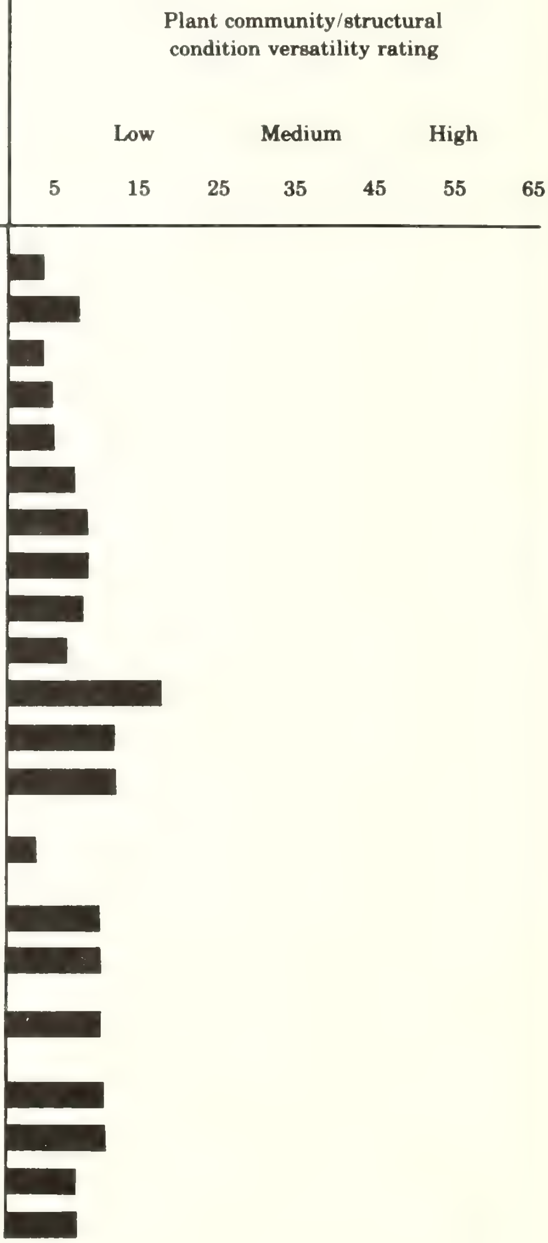


Appendix 11. Life form 3: reproduces on ground around water, or on floating, or emergent vegetation; feeds in water, on ground, in shrubs, and trees. (44 species)

		Reproductive orientation			Feeding orientation			
Letter code	Species	No. of plant communities used (1)	No. of structural conditions used (2)	Columns 1 & 2 (3)	No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	REPTILES							
THST	common garter snake	12	15	27	14	15	29	56
THEL	wandering garter snake	7	15	22	9	15	24	46
	BIRDS							
POAU	horned grebe	1	3	4	1	5	6	10
PONIGR	eared grebe	1	3	4	1	5	6	10
AEOC	western grebe	1	4	5	1	0	1	6
POPO	pied-billed grebe	1	5	6	1	5	6	12
PHAU	double-crested cormorant	2	6	8	1	0	1	9
BOLE	American bittern	1	5	6	1	10	11	17
IXEX	least bittern	1	5	6	1	10	11	17
BRCA	Canada goose	1	2	3	1	2	3	6
ANPL	mallard	1	7	8	2	8	10	18
ANSTR	gadwall	1	7	8	2	8	10	18
ANAC	common pintail	1	7	8	2	8	10	18
ANCR	green-winged teal	1	7	8	2	8	10	18
ANDIS	blue-winged teal	1	7	8	2	8	10	18
ANCY	cinnamon teal	1	7	8	2	8	10	18
ANAMEO	American wigeon	1	7	8	2	8	10	18
ANCL	northern shoveler	1	7	8	2	8	10	18

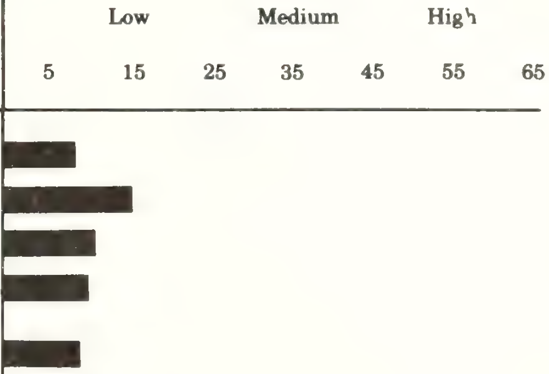


Letter code	Species	Reproductive orientation			Feeding orientation			
		No. of plant communities used (1)	No. of structural conditions used (2)	Columns 1 & 2 (3)	No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
AYAM	redhead	1	1	2	1	1	2	4
AYCO	ring-necked duck	1	2	3	2	3	5	8
AYVA	canvasback	1	1	2	1	1	2	4
AYAF	lesser scaup	1	1	2	1	2	3	5
OXJA	ruddy duck	1	1	2	1	2	3	5
GRCA	sandhill crane	2	1	3	3	2	5	8
RALI	Virginia rail	1	3	4	2	4	6	10
POCAR	sora	1	3	4	2	4	6	10
FUAM	American coot	1	3	4	1	4	5	9
CHALE	snowy plover	0	1	1	3	2	5	6
CHVO	killdeer	3	6	9	3	6	9	18
CAGA	common snipe	3	3	6	3	4	7	13
ACMA	spotted sandpiper	1	4	5	1	7	8	13
TRME	greater yellowlegs	1	1	2	1	1	2	4
REAM	American avocet	3	1	4	3	4	7	11
HIME	black-necked stilt	1	3	4	1	6	7	11
STTRI	Wilson's phalarope	1	3	4	1	6	7	11
LACA	California gull	1	2	3	3	5	8	11
LAPI	Franklin's gull	1	2	3	3	5	8	11
STFO	Forster's tern	1	2	3	1	5	6	9
STCAS	Caspian tern	1	2	3	1	5	6	9



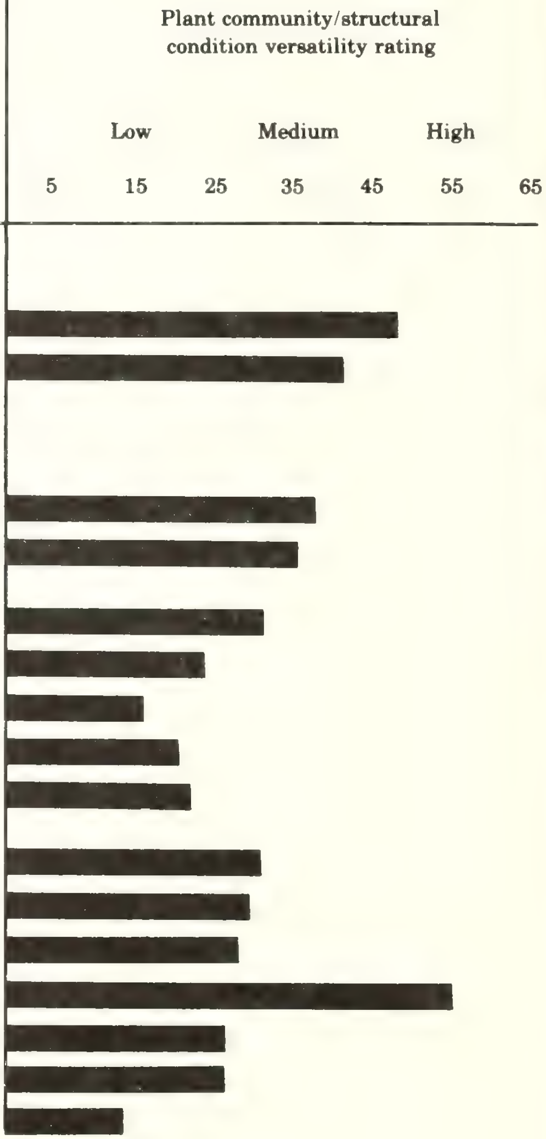
Letter code	Species	Reproductive orientation No. of plant communities used (1)	Reproductive orientation No. of structural conditions used (2)	Reproductive orientation Columns 1 & 2 (3)	Feeding orientation No. of plant communities used (4)	Feeding orientation No. of structural conditions used (5)	Feeding orientation Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
CHNI	black tern	1	2	3	1	5	6	9
CIME	dipper	1	5	6	1	9	10	16
CIPA	marsh wren	1	5	6	1	5	6	12
GETR	common yellowthroat	1	2	3	1	7	8	11
XAXA	yellow-headed blackbird	1	4	5	1	4	5	10
						Total		581
						$\overline{X}$ =		13.20

Plant community/structural condition versatility rating



Appendix 11. Life form 4: reproduces in cliffs, caves, rims, and/or talus; feeds on ground or in air. (33 species)

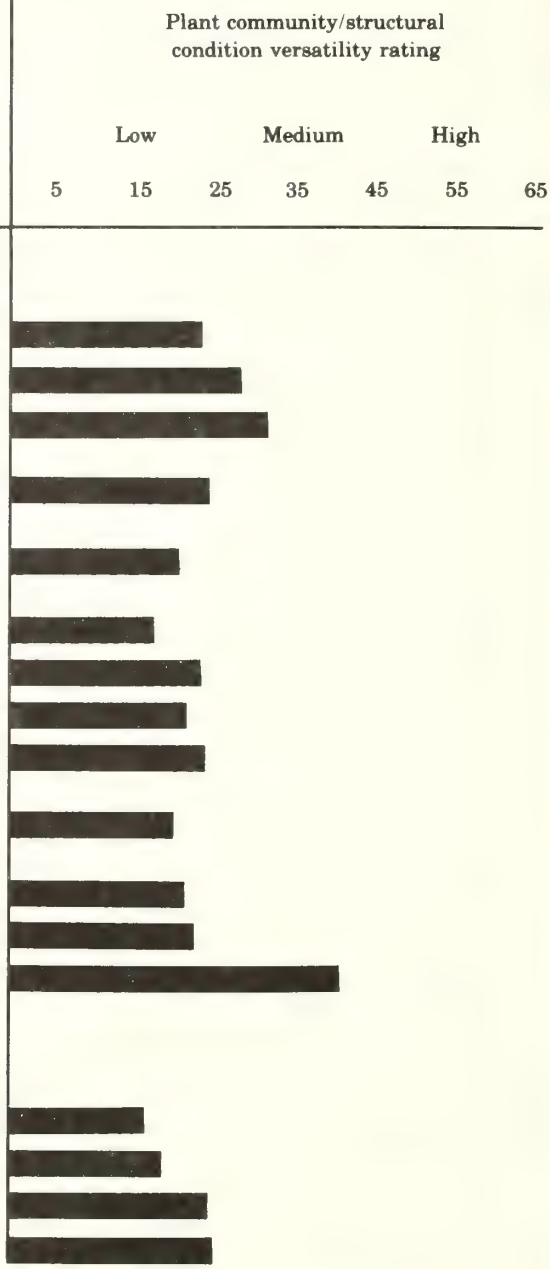
Letter code	Species	Reproductive orientation: No. of plant communities used (1)	Reproductive orientation: No. of structural conditions used (2)	Reproductive orientation: Columns 1 & 2 (3)	Feeding orientation: No. of plant communities used (4)	Feeding orientation: No. of structural conditions used (5)	Feeding orientation: Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	REPTILES							
CRCO	collared lizard	9	15	24	9	15	24	48
SCOC	western fence lizard	6	15	21	6	15	21	42
	BIRDS							
CAAU	turkey vulture	3	5	8	15	15	30	38
BUREG	ferruginous hawk	7	9	16	10	10	20	36
FAME	prairie falcon	2	10	12	10	10	20	32
ALCH	chukar	3	3	6	9	10	19	25
COLI	rock dove	3	4	7	2	8	10	17
CYNI	black swift	2	5	7	5	10	15	22
AESA	white-throated swift	3	5	8	5	10	15	23
SASA	Say's phoebe	6	5	11	10	10	20	31
HIRU	barn swallow	4	5	9	11	10	21	30
PEPY	cliff swallow	2	5	7	11	10	21	28
COCOR	common raven	15	10	25	15	15	30	55
CAMEXO	canyon wren	3	10	13	4	10	14	27
SAOB	rock wren	3	10	13	4	10	14	27
LEAT	black rosy finch	1	3	4	1	10	11	15



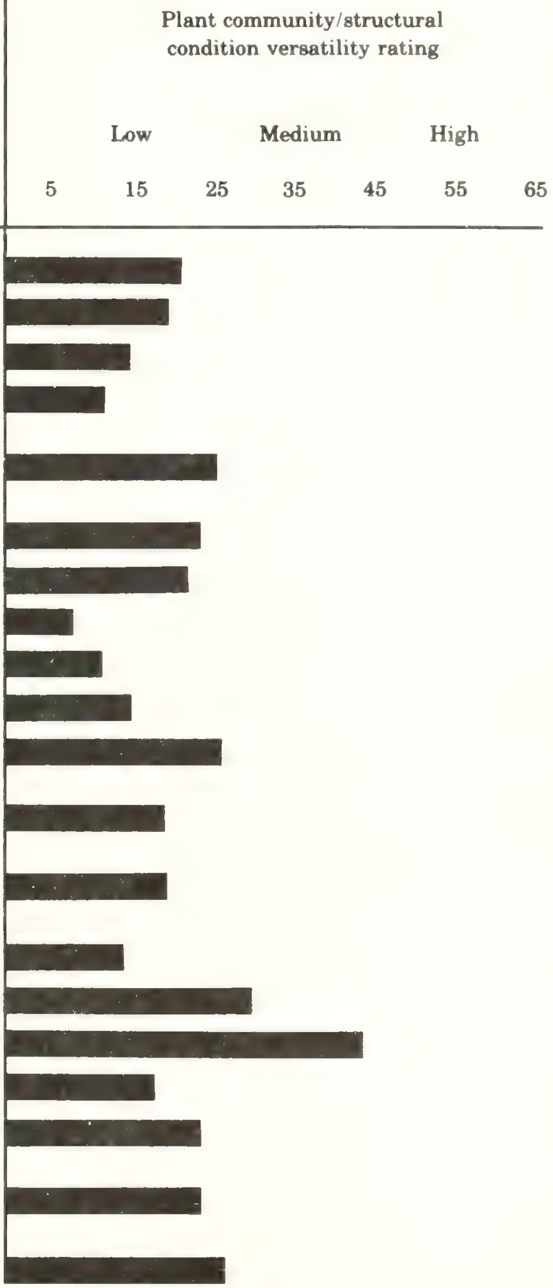
Letter code	Species	Reproductive orientation			Feeding orientation			
		No. of plant communities used (1)	No. of structural conditions used (2)	Columns 1 & 2 (3)	No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	MAMMALS							
MYLU	little brown myotis	3	10	13	3	12	15	28
MYTH	fringed myotis	2	10	12	2	11	13	25
MYCA	California myotis	3	10	13	3	11	14	27
MYLE	small-footed myotis	2	10	12	2	10	12	24
PIHE	western pipistrelle	2	10	12	2	11	13	25
EPFU	big brown bat	3	10	13	3	11	14	27
EUMAC	spotted bat	2	4	6	2	4	6	12
PLTO	western big-eared bat	2	10	12	2	13	15	27
ANPA	pallid bat	3	10	13	3	12	15	28
MAFL	yellow-bellied marmot	12	4	16	12	4	16	32
PECR	canyon mouse	3	11	14	3	11	14	28
NELE	desert woodrat	4	11	15	4	11	15	30
NECI	bushy-tailed woodrat	2	11	13	9	11	20	33
ERDO	porcupine	6	4	10	6	8	14	24
SPPU	spotted skunk	3	10	13	3	12	15	28
FECO	cougar	5	6	11	9	6	15	26
LYRU	bobcat	12	6	18	15	6	21	39
						Total		959
						$\overline{X}$ =		29.0

Appendix 11. Life form 5: reproduces on ground without specific water, cliff, rim, or talus association; feeds on ground. (45 species)

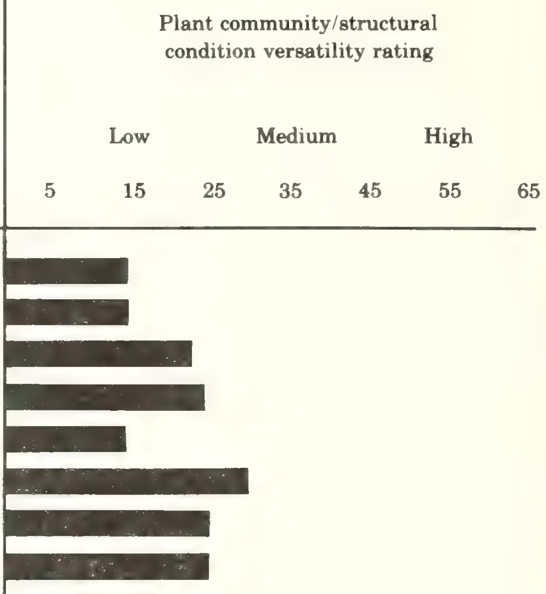
Letter code	Species	Reproductive orientation: No. of plant communities used (1)	Reproductive orientation: No. of structural conditions used (2)	Reproductive orientation: Columns 1 & 2 (3)	Feeding orientation: No. of plant communities used (4)	Feeding orientation: No. of structural conditions used (5)	Feeding orientation: Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	REPTILES							
CRWI	leopard lizard	4	8	12	4	8	12	24
SCGR	sagebrush lizard	5	8	13	5	10	15	28
UTST	side-blotched lizard	5	8	13	5	14	19	32
PHPL	desert horned lizard	5	7	12	5	8	13	25
PHDO	short-horned lizard	3	7	10	3	8	11	21
EUSK	western skink	3	4	7	3	8	11	18
CNTI	western whiptail	6	6	12	6	6	12	24
CHBO	rubber boa	2	8	10	2	10	12	22
COCONS	yellow-bellied racer	4	8	12	4	8	12	24
MATA	striped whipsnake	1	8	9	1	10	11	20
PIME	gopher snake	5	4	9	5	7	12	21
HYTO	night snake	4	5	9	4	10	14	23
CRVI	western rattlesnake	13	5	18	13	10	23	41
	BIRDS							
CICY	northern harrier	4	3	7	5	5	10	17
DEOB	blue grouse	5	3	8	5	6	11	19
BOUM	ruffed grouse	5	4	9	8	8	16	25
CEUR	sage grouse	2	8	10	8	8	16	26



Letter code	Species	Reproductive orientation			Feeding orientation			
		No. of plant communities used (1)	No. of structural conditions used (2)	Columns 1 & 2 (3)	No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
LOCA	California quail	8	3	11	8	3	11	22
ORPI	mountain quail	2	4	6	6	8	14	20
PEPER	gray partridge	3	2	5	5	6	11	16
PHCOL	ring-necked pheasant	2	4	6	2	4	6	12
NUAM	long-billed curlew	4	6	10	6	10	16	26
ASFL	short-eared owl	4	2	6	8	10	18	24
ERAL	horned lark	2	5	7	6	10	16	23
CAFU	veery	1	3	4	1	3	4	8
WIPU	Wilson's warbler	3	3	6	3	3	6	12
DOOR	bobolink	3	5	8	3	5	8	16
STNEG	western meadowlark	6	2	8	9	10	19	27
PASA	savannah sparrow	1	4	5	4	10	14	19
AMSA	grasshopper sparrow	1	4	5	4	10	14	19
POGRA	vesper sparrow	1	4	5	4	6	10	15
CHGR	lark sparrow	5	4	9	11	10	21	30
JUHY	northern junco	12	8	20	14	10	24	44
SYID	pygmy rabbit	5	4	9	5	4	9	18
SYNU	mountain cottontail	8	4	12	8	4	12	24
LETO	white-tailed jackrabbit	1	5	6	9	9	18	24
LECA	black-tailed jackrabbit	2	4	6	13	8	21	27

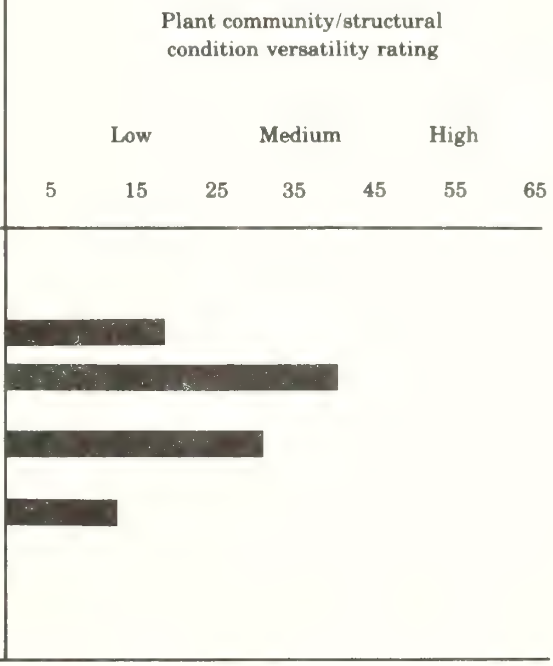


		Reproductive orientation			Feeding orientation			
Letter code	Species	No. of plant communities used (1)	No. of structural conditions used (2)	Columns 1 & 2 (3)	No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
RARA	black rat	4	4	8	4	4	8	16
RANO	Norway rat	4	4	8	4	4	8	16
FECA	feral house cat	3	4	7	5	10	15	22
EQUA	feral horse	4	8	12	5	8	13	25
CEEL	elk	3	2	5	7	4	11	16
ODHE	mule deer	5	2	7	14	9	23	30
ANAMER	pronghorn	2	3	5	10	10	20	25
OVCA	bighorn sheep	3	3	6	10	9	19	25
						Total		101
						$\overline{X}$ =		22.5



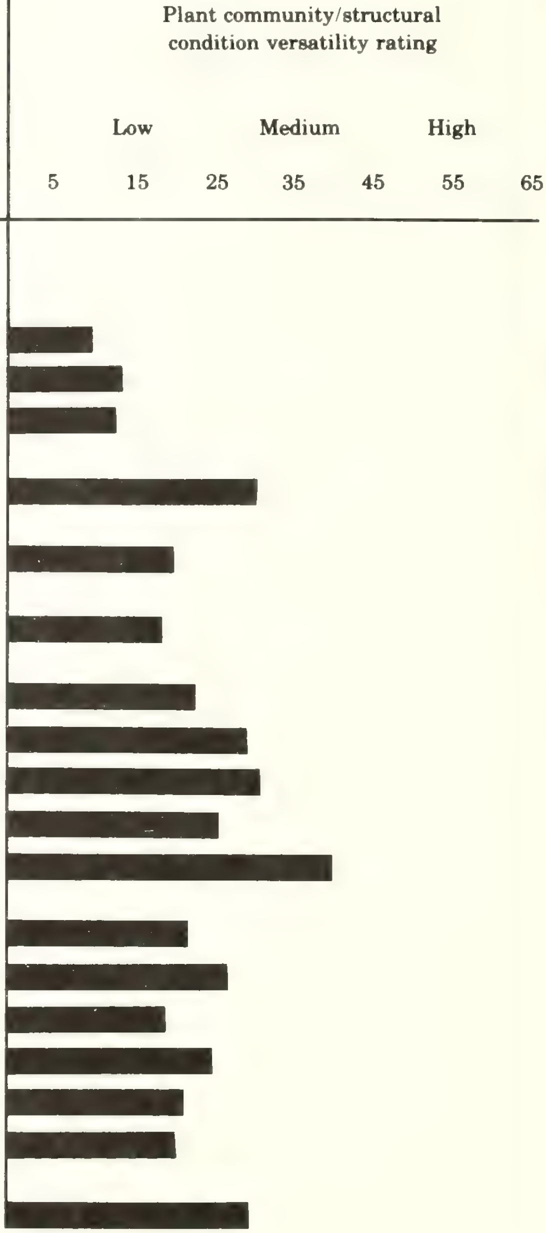
Appendix 11. Life form 6: reproduces on ground; feeds in shrubs, trees, or air. (4 species)

		Reproductive orientation			Feeding orientation			
Letter code	**Species**	**No. of plant communities used** (1)	**No. of structural conditions used** (2)	**Columns 1 & 2** (3)	**No. of plant communities used** (4)	**No. of structural conditions used** (5)	**Columns 4 & 5** (6)	**Versatility score columns 3 & 6** (7)
	BIRDS							
PHNU	poorwill	2	2	4	8	8	16	20
CHMI	common nighthawk	5	8	13	14	14	28	41
MYTO	Townsend's solitaire	4	8	12	12	8	20	32
VECE	orange-crowned warbler	3	4	7	3	4	7	14
						Total		107
						$\overline{X}$ =		26.8

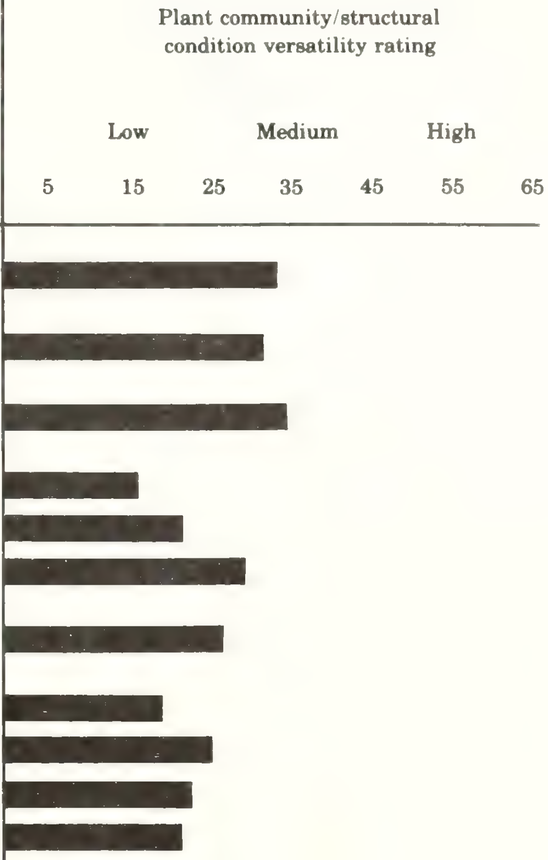


Appendix 11. Life form 7: reproduces in shrubs; feeds on ground, in water or air. (29 species)

Letter code	Species	Reproductive orientation: No. of plant communities used (1)	Reproductive orientation: No. of structural conditions used (2)	Reproductive orientation: Columns 1 & 2 (3)	Feeding orientation: No. of plant communities used (4)	Feeding orientation: No. of structural conditions used (5)	Feeding orientation: Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	BIRDS							
BUST	green heron	1	3	4	1	4	5	9
BUIB	cattle egret	3	3	6	5	4	9	15
NYNY	black-crowned night heron	3	3	6	5	3	8	14
BUSW	Swainson's hawk	5	6	11	10	10	20	31
STCAL	calliope hummingbird	5	3	8	7	5	12	20
CAAN	Anna's hummingbird	5	3	8	7	4	11	19
TYTY	eastern kingbird	6	3	9	8	7	15	24
EMTR	willow flycatcher	3	6	9	12	8	20	29
EMWR	gray flycatcher	7	6	13	12	6	18	31
APCO	scrub jay	6	4	10	10	6	16	26
PIPI	black-billed magpie	9	6	15	15	10	25	40
DUCA	gray catbird	3	4	7	9	6	15	22
TORV	brown thrasher	6	4	10	11	6	17	27
ORMO	sage thrasher	4	4	8	7	4	11	19
TUMI	American robin	3	6	9	9	8	17	26
CAUS	Swainson's thrush	4	4	8	8	6	14	22
PACAE	blue-gray gnatcatcher	3	6	9	6	6	12	21
LALU	loggerhead shrike	5	5	10	12	8	20	30

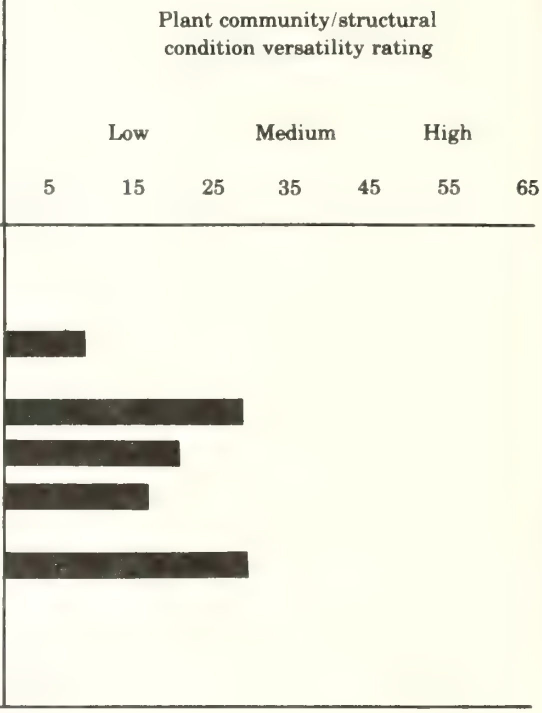


Letter code	Species	Reproductive orientation No. of plant communities used (1)	 No. of structural conditions used (2)	 Columns 1 & 2 (3)	Feeding orientation No. of plant communities used (4)	 No. of structural conditions used (5)	 Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
AGPH	red-winged blackbird	6	5	11	14	8	22	33
EUCY	Brewer's blackbird	7	15	12	14	5	19	31
MOAT	brown-headed cowbird	7	7	14	14	7	21	35
PAAMO	lazuli bunting	3	4	7	4	6	10	17
CAPS	lesser goldfinch	4	2	6	8	8	16	22
PICH	green-tailed towhee	6	6	12	11	6	7	29
PIER	rufous-sided towhee	6	6	12	9	6	15	27
AMBE	sage sparrow	5	4	9	5	6	11	20
SPPA	chipping sparrow	5	6	11	9	6	15	26
SPBRE	Brewer's sparrow	4	6	10	5	8	13	23
NEMEL	song sparrow	4	4	8	11	4	14	22
							Total	710
							$\overline{X}$ =	24.5



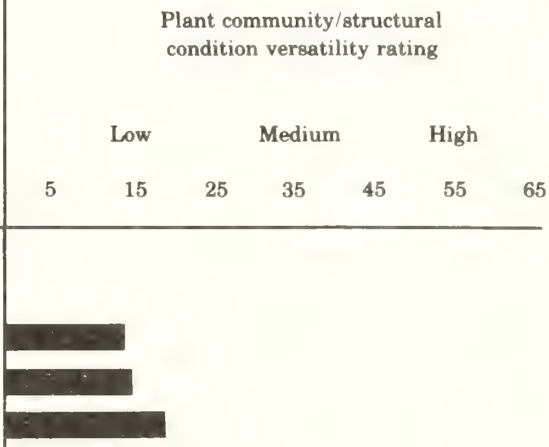
Appendix 11. Life form 8: reproduces in shrubs; feeds in shrubs, trees, or air. (5 species)

		Reproductive orientation			Feeding orientation			
Letter code	Species	No. of plant communities used (1)	No. of structural conditions used (2)	Columns 1 & 2 (3)	No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	BIRDS							
COAM	yellow-billed cuckoo	1	4	5	1	4	5	10
PSMI	bushtit	5	4	9	12	8	20	29
DEPE	yellow warbler	2	6	8	8	6	14	22
ICVI	yellow-breasted chat	3	4	7	7	4	11	18
CATR	American goldfinch	4	6	10	9	8	17	27
							Total	106
							X –	21.2



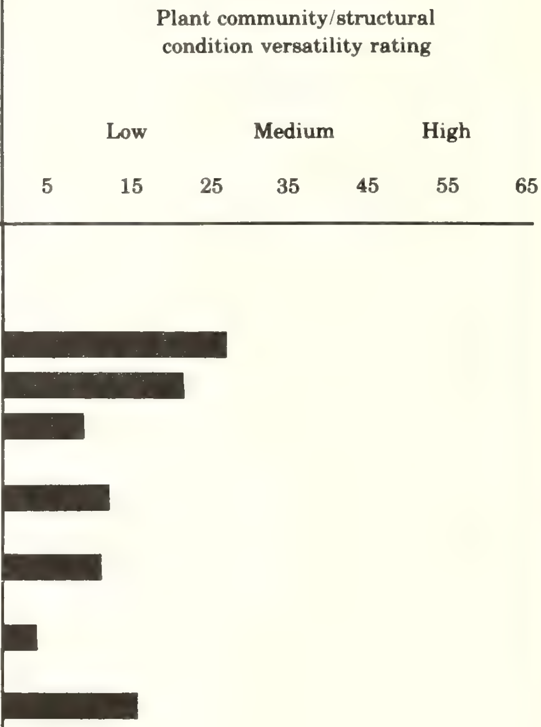
Appendix 11. Life form 9: reproduces primarily in deciduous trees; feeds in shrubs, trees, or air. (3 species)

Letter code	Species	Reproductive orientation: No. of plant communities used (1)	Reproductive orientation: No. of structural conditions used (2)	Reproductive orientation: Columns 1 & 2 (3)	Feeding orientation: No. of plant communities used (4)	Feeding orientation: No. of structural conditions used (5)	Feeding orientation: Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	BIRDS							
BOCE	cedar waxwing	3	3	6	5	5	10	16
ICGA	northern oriole	3	4	7	4	6	10	17
CAMEXI	house finch	5	2	7	9	4	13	20
						Total		53
						$\overline{X}$ =		17.7



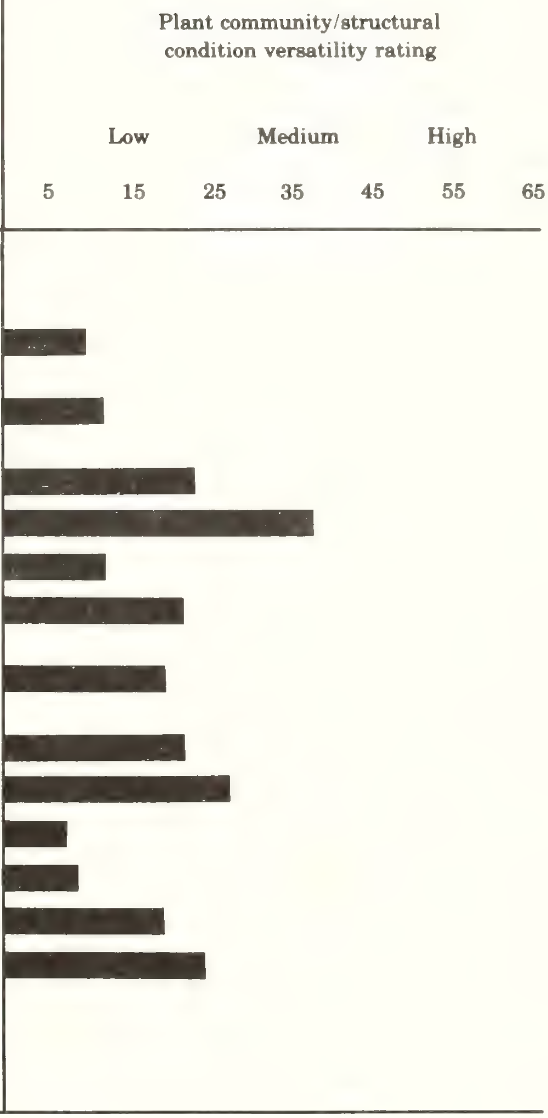
Appendix 11. Life form 10: reproduces primarily in conifers; feeds in shrubs, trees, or air. (7 species)

		Reproductive orientation			Feeding orientation			
Letter code	Species	No. of plant communities used (1)	No. of structural conditions used (2)	Columns 1 & 2 (3)	No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	BIRDS							
EMDI	western flycatcher	4	6	10	9	8	17	27
GYCY	pinyon jay	1	6	7	9	6	15	22
RECA	ruby-crowned kinglet	3	2	5	3	2	5	10
DECOR	yellow-rumped warbler	4	2	6	5	2	7	13
DENI	black-throated gray warbler	1	2	3	5	4	9	12
DETO	Townsend's warbler	1	1	2	1	1	2	4
PILU	western tanager	3	2	5	4	8	12	17
						Total		105
						$\bar{X}$ =		15.0



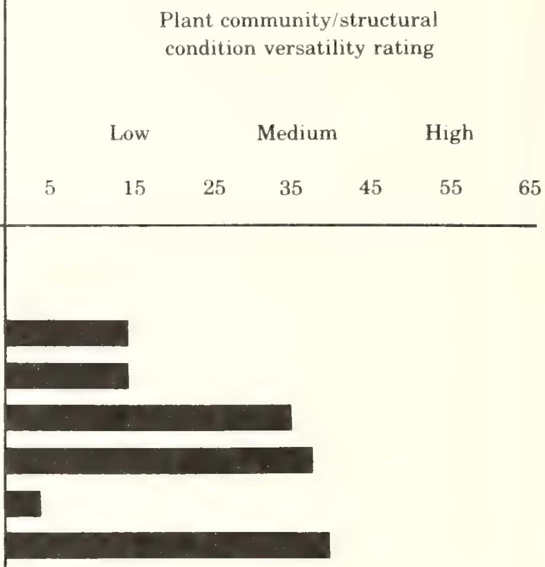
Appendix 11. Life form 11: reproduces in trees; feeds on ground, in shrubs, trees, or air. (13 species)

Letter code	Species	Reproductive orientation: No. of plant communities used (1)	Reproductive orientation: No. of structural conditions used (2)	Reproductive orientation: Columns 1 & 2 (3)	Feeding orientation: No. of plant communities used (4)	Feeding orientation: No. of structural conditions used (5)	Feeding orientation: Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	BIRDS							
ACGE	northern goshawk	2	2	4	3	4	7	11
ACST	sharp-shinned hawk	3	2	5	4	4	8	13
ACCO	Cooper's hawk	3	4	7	8	8	16	23
ZEMA	mourning dove	10	8	18	15	5	20	38
ASOT	long-eared owl	3	3	6	4	3	7	13
TYVE	western kingbird	4	4	8	9	5	14	22
COSO	western wood pewee	3	3	6	9	5	14	20
CYST	Steller's jay	5	3	8	9	5	14	22
COBRA	American crow	5	4	9	14	5	19	28
VIOL	red-eyed vireo	3	1	4	3	1	4	8
VIGI	warbling vireo	3	2	5	3	2	5	10
CAPU	purple finch	4	2	6	11	3	14	20
SPARB	American tree sparrow	4	2	6	11	8	19	25
							Total	253
							$\overline{X}$ =	19.5



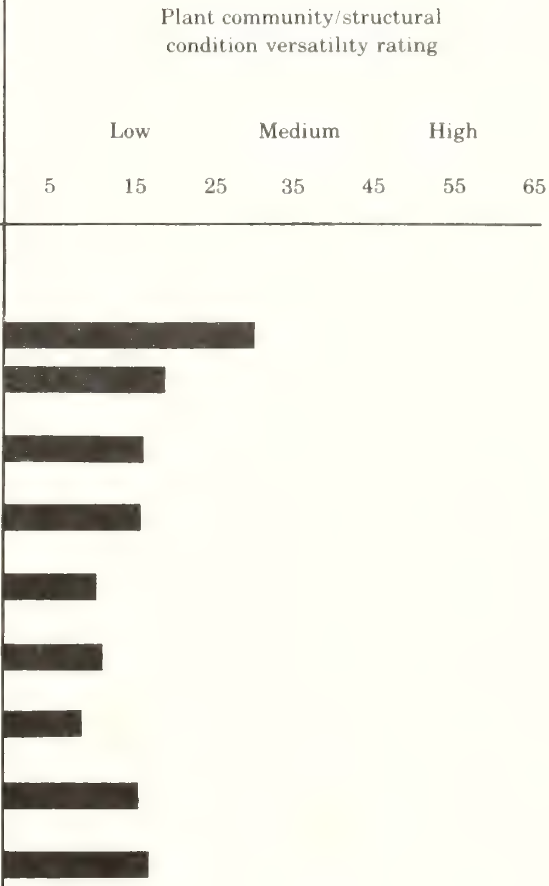
Appendix 11. Life form 12: reproduces on very thick branches; feeds on ground or in water. (6 species)

		Reproductive orientation			Feeding orientation			
Letter code	Species	No. of plant communities used (1)	No of structural conditions used (2)	Columns 1 & 2 (3)	No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	BIRDS							
ARHE	great blue heron	4	7	11	3	1	4	15
CAAL	common egret	4	7	11	3	1	4	15
BUJA	red-tailed hawk	6	6	12	14	10	24	36
AQCH	golden eagle	7	6	13	15	10	25	38
PAHA	osprey	1	2	3	1	0	1	4
BUVIR	great horned owl	9	6	15	15	10	25	40
							Total	148
							X̄ =	24.7



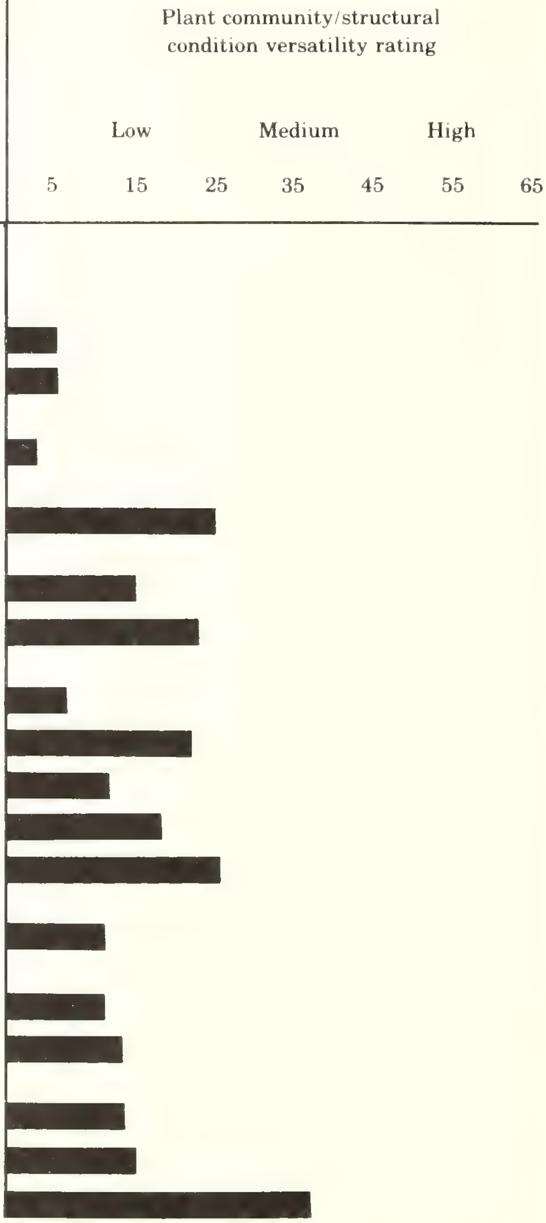
Appendix 11. Life form 13: reproduces – excavates own hole in a tree; feeds on ground, in shrubs, trees, or air. (9 species)

Letter code	Species	Reproductive orientation: No of plant communities used (1)	Reproductive orientation: No. of structural conditions used (2)	Reproductive orientation: Columns 1 & 2 (3)	Feeding orientation: No. of plant communities used (4)	Feeding orientation: No. of structural conditions used (5)	Feeding orientation: Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	BIRDS							
COAU	common flicker	4	6	10	12	9	21	31
MELE	Lewis' woodpecker	3	6	9	3	8	11	20
SPVAR	yellow-bellied sapsucker	4	4	8	4	5	9	17
SPTH	Williamson's sapsucker	4	4	8	4	5	9	17
PIVI	hairy woodpecker	4	2	6	4	2	6	12
PIPU	downy woodpecker	3	3	6	3	4	7	13
PIAL	white-headed woodpecker	1	3	4	3	3	6	10
SICAR	white-breasted nuthatch	1	6	7	4	6	10	17
SICAN	red-breasted nuthatch	2	6	8	4	6	10	18
							Total	155
							$\overline{X}$ =	17.2

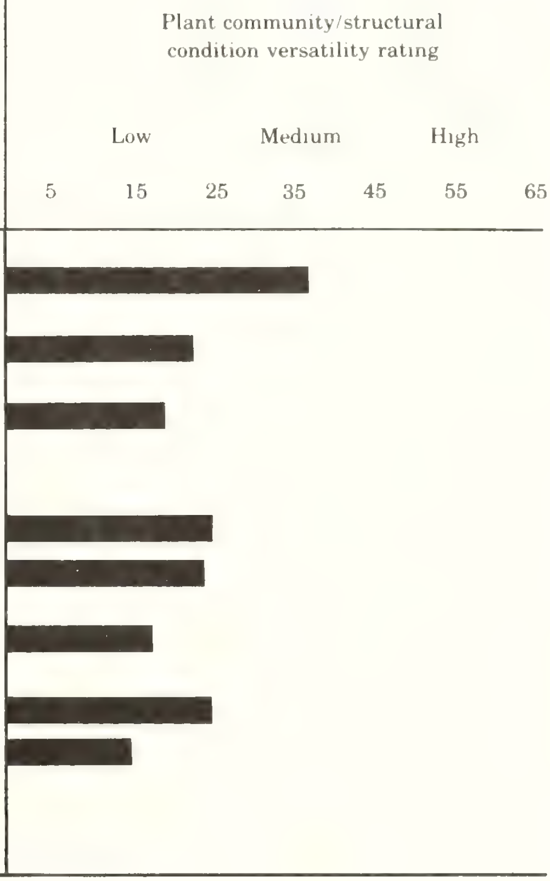


Appendix 11. Life form 14: reproduces in a hole made by another species or that has occurred naturally; feeds on ground, in water, or air. (25 species)

Letter code	Species	Reproductive orientation: No. of plant communities used (1)	Reproductive orientation: No. of structural conditions used (2)	Reproductive orientation: Columns 1 & 2 (3)	Feeding orientation: No. of plant communities used (4)	Feeding orientation: No. of structural conditions used (5)	Feeding orientation: Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	BIRDS							
AISP	wood duck	1	4	5	1	0	1	6
BUIS	Barrow's goldeneye	1	4	5	1	0	1	6
MEMER	common merganser	1	1	2	1	1	2	4
FASP	American kestrel	5	5	10	8	8	16	26
TYAL	barn owl	2	4	6	5	6	11	17
OTAS	common screech owl	5	4	9	9	6	15	24
OTFL	flammulated owl	2	2	4	2	2	4	8
GLGN	pygmy owl	4	4	8	9	6	15	23
AEAC	saw-whet owl	3	3	6	3	4	7	13
CHVA	Vaux's swift	1	4	5	6	9	15	20
MYCI	ash-throated flycatcher	5	4	9	10	8	18	27
TATH	violet-green swallow	3	2	5	5	3	8	13
IRBI	tree swallow	3	2	5	5	3	8	13
PAATR	black-capped chickadee	4	2	6	6	3	9	15
CEFA	brown creeper	4	2	6	6	3	9	15
TRAE	house wren	6	2	8	6	3	9	17
SIME	western bluebird	6	6	12	14	12	26	38

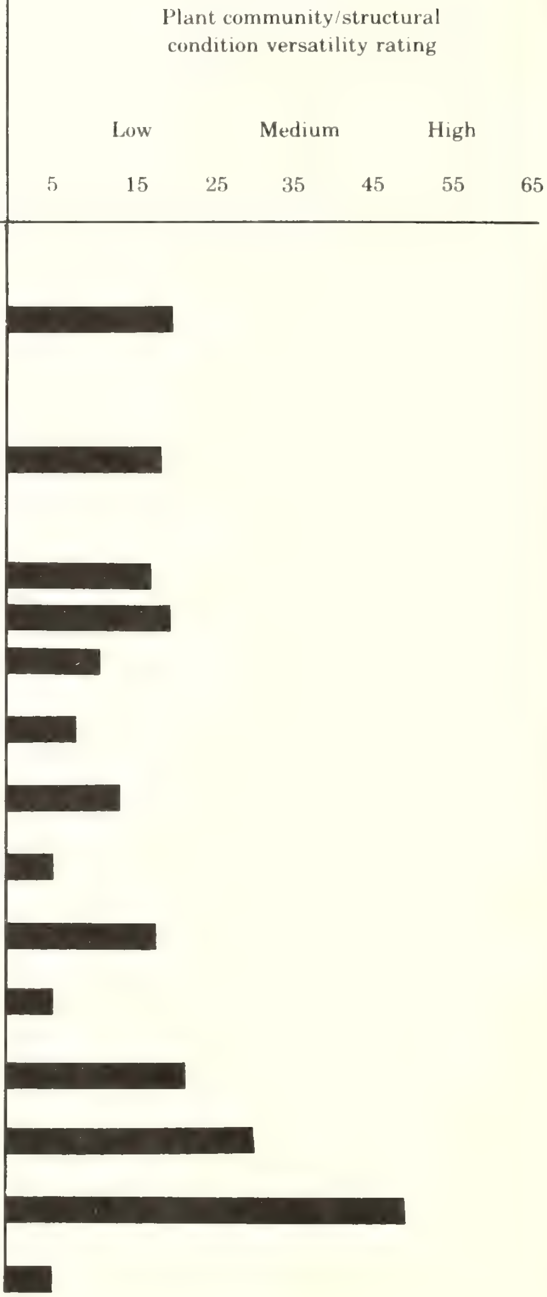


Letter code	Species	Reproductive orientation No. of plant communities used (1)	No of structural conditions used (2)	Columns 1 & 2 (3)	Feeding orientation No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
SICU	mountain bluebird	6	6	12	14	12	26	38
STVU	European starling	5	2	7	8	8	16	23
PADO	house sparrow	4	2	6	6	8	14	20
	MAMMALS							
MYYU	Yuma myotis	1	6	7	10	8	18	25
MYEV	long-eared myotis	0	6	6	10	8	18	24
MYVO	long-legged myotis	0	3	3	10	5	15	18
LANO	silver-haired bat	1	6	7	10	8	18	25
PRLO	raccoon	1	4	5	1	9	10	15
							Total	463
							$\overline{X}$ =	18.5

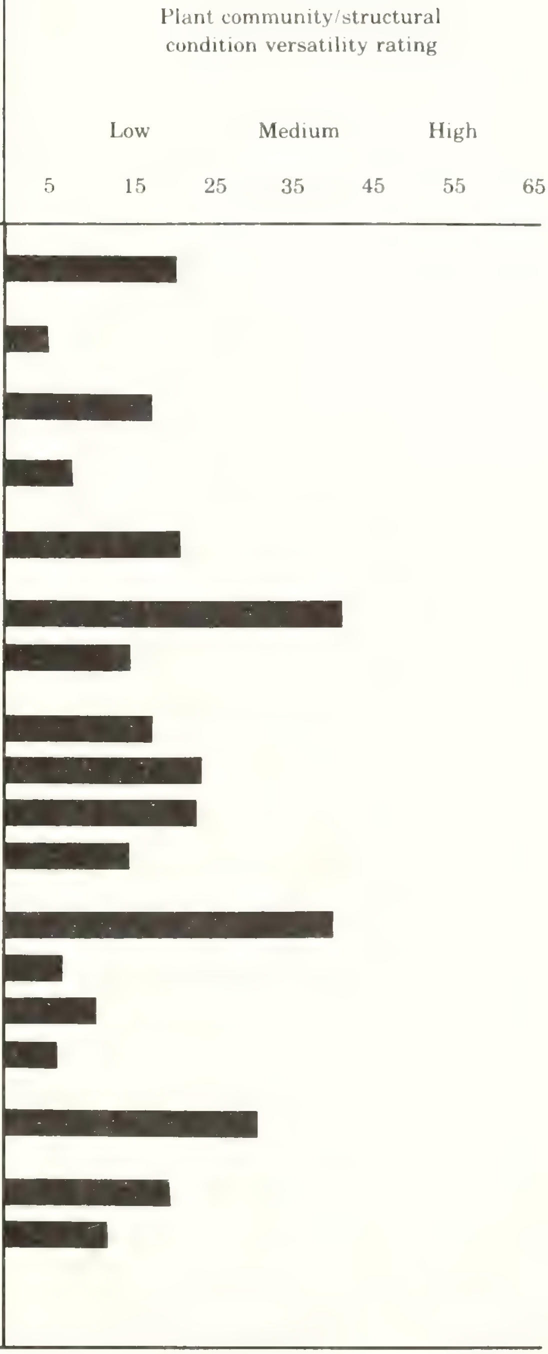


Appendix 11. Life form 15: reproduces underground in burrow; feeds on or under ground. (32 species)

Letter code	Species	Reproductive orientation: No. of plant communities used (1)	Reproductive orientation: No. of structural conditions used (2)	Reproductive orientation: Columns 1 & 2 (3)	Feeding orientation: No. of plant communities used (4)	Feeding orientation: No. of structural conditions used (5)	Feeding orientation: Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	REPTILES							
SOSE	western ground snake	4	4	8	4	8	12	20
	BIRDS							
ATCU	burrowing owl	3	4	7	8	4	12	19
	MAMMALS							
SOME	Merriam shrew	3	5	8	3	5	8	16
EUMI	least chipmunk	6	3	9	6	5	11	20
EUQM	yellow pine chipmunk	2	4	6	2	4	6	12
AMLE	antelope ground squirrel	2	2	4	2	2	4	8
SPTO	Townsend ground squirrel	3	4	7	3	4	7	14
SPRI	Richardson ground squirrel	1	2	3	1	2	3	6
SPBE	Belding ground squirrel	5	4	9	5	4	9	18
SPCO	Columbian ground squirrel	1	2	3	1	2	3	6
SPLA	mantled ground squirrel	6	4	10	6	6	12	22
THTO	Townsend pocket gopher	7	8	15	7	8	15	30
THTA	northern pocket gopher	15	10	25	15	10	25	50
PELO	little pocket mouse	1	2	3	1	2	3	6

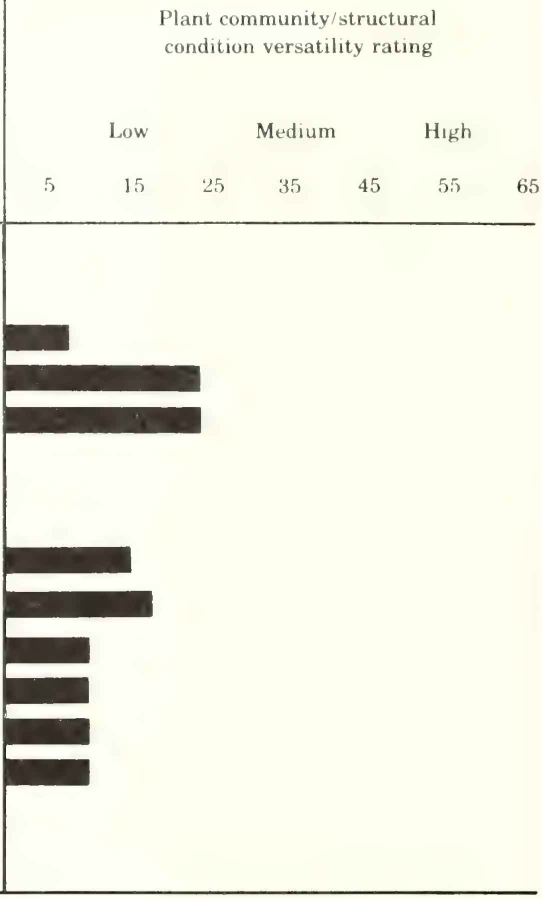


Letter code	Species	Reproductive orientation No. of plant communities used (1)	No. of structural conditions used (2)	Columns 1 & 2 (3)	Feeding orientation No. of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
PEPA	Great Basin pocket mouse	5	6	11	5	6	11	22
MIME	dark kangaroo mouse	1	2	3	1	2	3	6
DIOR	Ord kangaroo rat	3	6	9	3	6	9	18
DIMI	chisel-toothed kangaroo rat	2	2	4	2	2	4	8
REME	western harvest mouse	5	6	11	5	6	11	22
PEMA	deer mouse	15	6	21	15	6	21	42
ONLE	northern grasshopper mouse	2	6	8	2	6	8	16
MIMO	montane vole	4	5	9	4	5	9	18
MILO	long-tailed vole	6	6	12	6	6	12	24
LACU	sage vole	4	6	10	4	9	13	23
ZAPR	western jumping mouse	3	5	8	3	5	8	16
CALAT	coyote	13	6	19	14	8	22	41
VUVU	red fox	1	2	3	1	3	4	7
VUMA	kit fox	3	2	5	3	4	7	12
MUER	short-tailed weasel	1	2	3	1	3	4	7
MUFR	long-tailed weasel	9	6	15	9	7	16	31
TATA	badger	4	6	10	4	6	10	20
MEMEP	striped skunk	2	3	5	2	6	8	13
						Total		593
							$\bar{X}$ =	18.5



Appendix 11. Life form 16: reproduces underground in burrow; feeds in water, on ground, or in air. (9 species)

		Reproductive orientation			Feeding orientation			
Letter code	Species	No of plant communities used (1)	No of structural conditions used (2)	Columns 1 & 2 (3)	No of plant communities used (4)	No. of structural conditions used (5)	Columns 4 & 5 (6)	Versatility score columns 3 & 6 (7)
	BIRDS							
MEAL	belted kingfisher	1	6	7	1	0	1	8
RIRI	bank swallow	1	8	9	6	9	15	24
STRU	rough-winged swallow	1	8	9	6	9	15	24
	MAMMALS							
SOPR	Malheur shrew	3	5	8	3	5	8	16
SOVA	wandering shrew	4	5	9	4	5	9	18
CACAN	beaver	1	4	5	1	4	5	10
ONZI	muskrat	1	4	5	1	4	5	10
MUVI	mink	1	4	5	1	4	5	10
LUCA	river otter	1	4	5	1	4	5	10
						Total		130
						$\overline{X}$ =		14.4



Appendix 12. Life form versatility rating summary.

Life form[1]	Number of species[2]	Range of versatility scores	Mean versatility score	Life form[3] versatility rating (median scale)
1	2	12	12	low
2	6	11-31	19.2	medium
3	44	4-56	13.2	low
4	33	12-55	29.0	high
5	45	8-44	22.5	medium
6	4	14-41	26.8	high
7	29	9-40	24.5	high
8	5	10-29	21.2	medium
9	3	16-20	17.7	medium
10	10	4-27	15.0	low
11	13	8-38	19.5	medium
12	6	4-40	24.7	high
13	9	10-31	17.2	low
14	25	4-38	18.5	medium
15	32	6-50	18.5	medium
16	9	8-24	14.4	low

Total: 275
$\overline{X} = 19.8$

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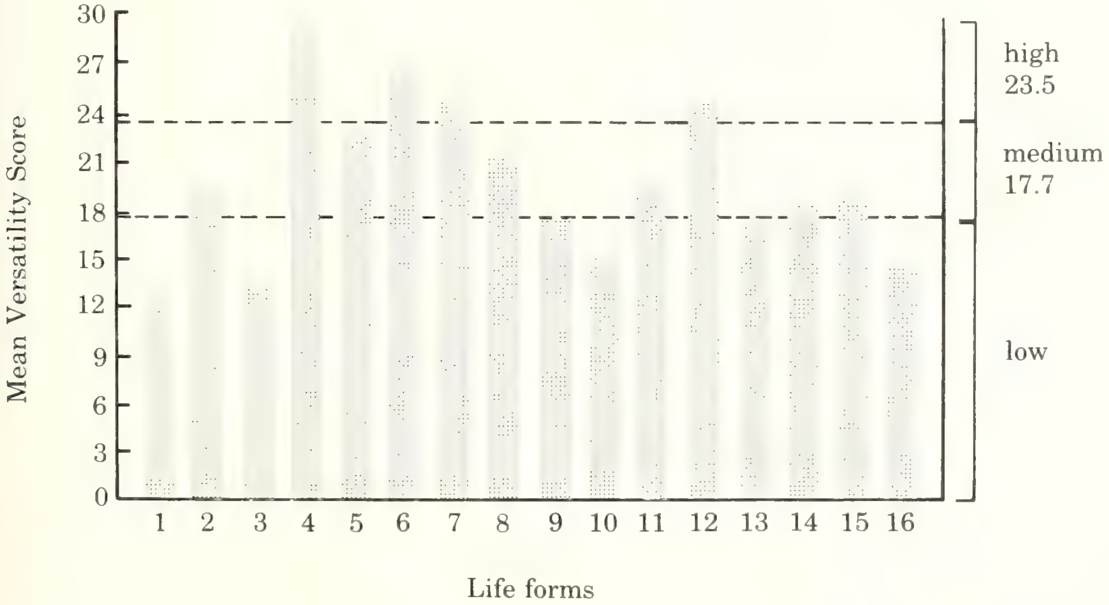
[1] See table 1 for life form descriptions.

[2] Refers to total number of species in life form.

[3] "Low" = 12.0-17.6, " medium" = 17.7-23.4, "high" = 23.5-29.0.



Appendix 13. 110 wildlife species in southeast Oregon of “special interest”

References

The following references were used, respectively, as sources for the 6 status classification columns in this appendix.

1. U.S. Fish and Wildlife Service. 1979. Endangered and threatened wildlife and plants: Republication of the list of species. Fed. Regist. 44(12) (Jan. 17):3636-3654.

2a. Oregon State Department of Fish and Wildlife. (1977). Oregon's threatened or endangered wildlife. (Ron Shay, ed.) 13 p. Oreg. Dep. Fish and Wildl., Portland.

2b. Shay, Ron. 1973. Oregon's rare or endangered wildlife. Oreg. State Game Comm. Bull. 29(1):3-8.

3. U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife. 1973. Threatened wildlife of the United States. (“Red Book”) Resour. Publ. 114, 289 p. Off. Endangered Species and Int. Act., Washington, D.C.

4. Dyrness, C. T., Jerry F. Franklin, Chris Maser, Stanton A. Cook, James D. Hall, and Glenda Faxon. 1975. Research Natural Area needs in the Pacific Northwest: A contribution to land-use planning. (“Yellow Book”) USDA For. Serv. Gen. Tech. Rep. PNW-38, 231 p. Pac. Northwest For. and Range Exp. Stn., Portland.

5a. Storm, Robert M. 1966. Endangered plants and animals of Oregon: II. Amphibians and reptiles. Agric. Exp. Stn. Spec. Rep. 206, 12 p. Oreg. State Univ., Corvallis.

5b. Marshall, David B. 1969. Endangered plants and animals of Oregon: III. Birds. Agric. Exp. Stn. Spec. Rep. 278, 23 p. Oreg. State Univ., Corvallis.

5c. Olterman, James H., and B. J. Verts. 1972. Endangered plants and animals of Oregon: IV. Mammals. Agric. Exp. Stn. Spec. Rep. 364, 47 p. Oreg. State Univ., Corvallis.

6. Arbib, Robert. 1978. The blue list for 1979. Am. Birds 32(6):1106-1113.

Appendix 13. Continued

		Species	1	2	3	4	5	6	7[1]	8[1]
		AMPHIBIANS								
RAPR	1	spotted frog[2]					X			
		REPTILES								
CRCO	4	collared lizard					X			
CRWI	5	leopard lizard					X			
PHDO	5	short-horned lizard					X			
CNTI	5	western whiptail				SI				
HYTO	5	night snake				SI				
CRVI	5	western rattlesnake				SI	X			
		BIRDS								
POGRI	3	red-necked grebe*				SI	P	X		
AEOC	3	western grebe						X		
PEER	3	American white pelican*					R	X		
PHAU	3	double-crested cormorant						X		
NYNY	7	black-crowned night heron						X		
BOLE	3	American bittern				SI		X		
PLCH	7	white-faced ibis*			SU	SI	P	X		
BRCA	3	Canada goose[3]		E		SI	E			
ANAL	3	white-fronted goose[4]*					E			
AYCO	3	ring-necked duck					P			
AYVA	3	canvasback						X		
AYAF	3	lesser scaup					P			
BUIS	14	Barrow's goldeneye					P			
BUALBE	14	bufflehead					P			

Letter code	Life form	E – Endangered P – Peripheral R – Rare SI – Species of special interest SU – Status undetermined T – Threatened U – Unique X – Occurs on list	Federal Register (endangered) 1	Oregon State (endangered or threatened) 2 (a & b)	U.S. Dep. Inter. Fish & Wildl. Serv. "Red Book" 3	USDA FS RNA "Yellow Book" 4	OSU endangered plants and animals of Oregon 5 (a)	Audubon – Blue list for 1979 6	7	8

NOTE: See footnotes at end of appendix 13, p. 207.

Appendix 13. Continued

		Species	1	2	3	4	5	6	7	8
CAAU	4	turkey vulture				SI				
ACST	11	sharp-shinned hawk						X		
ACCO	11	Cooper's hawk						X		
BUJA	12	red-tailed hawk[5]				SI				
BUSW	7	Swainson's hawk					R	X		
BULA	4	rough-legged hawk				SI				
BUREG	4	ferruginous hawk				SI	E	X		
AQCH	12	golden eagle				SI				
HALE	12	bald eagle*	T	T		SI	E			
CICY	5	northern harrier						X		
PAHA	12	osprey			SU	SI	R	X		
FAME	4	prairie falcon			T	SI	R	X		
FAPE	4	peregrine*	E	E	T	SI	E			
FACO	11	merlin*				SI	E	X		
FASP	14	American kestrel[6]				SI		X		
CEUR	5	sage grouse						X		
GRCA	3	sandhill crane				SI	E			
RALI	3	Virginia rail				SI				
CHALE	3	snowy plover		T		SI	R	X		
CHMO	3	mountain plover*				SI				
NUAM	3	long-billed curlew			SU	SI				
TRSO	7	solitary sandpiper*				SI				
CASE	3	willet*				SI				
CABA	3	Baird's sandpiper*				SI				
LAPI	3	Franklin's gull				SI	SU			
STCAS	3	Caspian tern				SI	SU			
CHNI	3	black tern						X		
COAM	8	yellow-billed cuckoo				SI	SU	X		
TYAL	14	barn owl						X		
OTAS	14	common screech owl				SI	SU			
Letter code	Life form	E – Endangered P – Peripheral R – Rare SI – Species of special interest SU – Status undetermined T – Threatened U – Unique X – Occurs on list	Federal Register (endangered)	Oregon State (endangered or threatened)	U.S. Dep. Inter. Fish & Wildl. Serv. "Red Book"	USDA FS RNA "Yellow Book"	OSU endangered plants and animals of Oregon	Audubon – Blue list for 1979		
			1	2	3	4	5	6	7	8
				(a & b)			(a)			

Appendix 13. Continued

		Species	1	2	3	4	5	6	7	8
OTFL	14	flammulated owl				SI	SU			
ATCU	15	burrowing owl			SU	SI		X		
ASFL	5	short-eared owl						X		
PHNU	6	poorwill				SI	SU			
CHMI	6	common nighthawk						X		
PILE	13	Lewis' woodpecker						X		
PIVI	13	hairy woodpecker						X		
SICAN	13	red-breasted nuthatch				SI				
MIPO	7	northern mockingbird				SI	P			
DUCA	7	gray catbird				SI	P			
CAGN	5	hermit thrush				SI				
CAFU	5	veery				SI	P			
SIME	14	western bluebird				SI		X		
ANSP	5	water pipit				SI	P			
BOGA	9	Bohemian waxwing				SI	P			
LALU	7	loggerhead shrike						X		
VIOL	11	red-eyed vireo				SI				
VIGI	11	warbling vireo				SI		X		
VECE	6	orange-crowned warbler				SI				
DEPE	8	yellow warbler						X		
DECOR	10	yellow-rumped warbler				SI				
DENI	10	black-throated gray warbler				SI				
OPTO	7	MacGillivray's warbler				SI				
GETR	3	common yellowthroat				SI				
ICVI	8	yellow-breasted chat						X		
SERUT	9	American redstart				SI	P			
DOOR	5	bobolink				SI	P			
STNEG	5	western meadowlark				SI				
PAAMO	7	lazuli bunting				SI				
AMSA	5	grasshopper sparrow						X		
Letter code	Life form	E – Endangered P – Peripheral R – Rare SI – Species of special interest SU – Status undetermined T – Threatened U – Unique X – Occurs on list	Federal Register (endangered) 1	Oregon State (endangered or threatened) 2	U.S. Dep. Inter. Fish & Wildl. Serv. "Red Book" 3	USDA FS RNA "Yellow Book" 4	OSU endangered plants and animals of Oregon 5	Audubon – Blue list for 1979 6	7	8
				(a & b)			(a)			

Appendix 13. Continued

		Species	1	2	3	4	5	6	7	8
AMBI	7	black-throated sparrow								
POGRA	5	vesper sparrow				SI		X		
JUHY	5	northern junco				SI				
PAIL	7	fox sparrow*				SI				
		MAMMALS								
SOPR	16	Malheur shrew				R	R			
SOME	15	Merriam shrew				R	R			
MYEV	14	long-eared myotis				U				
MYTH	4	fringed myotis				R	SU			
MYVO	14	long-legged myotis				R				
MYLE	4	small-footed myotis				R				
LANO	14	silver-haired bat				R				
PIHE	4	western pipistrelle					SU			
LACI	11	hoary bat				R	X			
EUMA	4	spotted bat			T					
ANPA	4	pallid bat				R				
SYID	5	pygmy rabbit				T	X			
LETO	5	white-tailed jackrabbit				U	X			
AMLE	15	antelope ground squirrel					X			
SPRI	15	Richardson ground squirrel				R	X			
PELO	15	little pocket mouse				R				
MIME	15	dark kangaroo mouse					X			
ONLE	15	northern grasshopper mouse				SI X				
LACU	15	sage vole					X			
VUVU	15	red fox				R				
VUMA	15	kit fox		T	T	T	E			
TATA	15	badger					X			
Letter code	Life form	E – Endangered P – Peripheral R – Rare SI – Species of special interest SU – Status undetermined T – Threatened U – Unique X – Occurs on list	Federal Register (endangered) 1	Oregon State (endangered or threatened) 2	U.S. Dep. Inter. Fish & Wildl. Serv. "Red Book" 3	USDA FS RNA "Yellow Book" 4	OSU endangered plants and animals of Oregon 5	Audubon – Blue list for 1979 6	7	8
				(a & b)			(a)			

Appendix 13. Continued

		Species	1	2	3	4	5	6	7	8
LUCA	16	river otter					X			
FECO	4	puma					X			
OVCA	5	bighorn sheep				U	R			

Letter code	Life form	E – Endangered P – Peripheral R – Rare SI – Species of special interest SU – Status undetermined T – Threatened U – Unique X – Occurs on list	Federal Register (endangered) 1	Oregon State (endangered or threatened) 2	U.S. Dep. Inter. Fish & Wildl. Serv. "Red Book" 3	USDA FS RNA "Yellow Book" 4	OSU endangered plants and animals of Oregon 5	Audubon – Blue list for 1979 6	7	8
				(a & b)			(a)			

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[1] Columns 7 and 8 have been left blank so that field biologists can fill them in as may be required for local planning efforts.

[2] Population: Western spotted frog.

[*] May feed in southeast Oregon but is not known to reproduce there. Shown on this list but not on the individual life form lists in other appendices. These are the 12 species listed in appendix 5.

[3] Subspecies: Aleutian Canada goose (*Branta canadensis leucoparela*) may occur in winter.

[4] Subspecies: Tule white-fronted goose (*Anser albifrons gambelli*).

[5] Subspecies: Alaska red-tailed hawk.

[6] Subspecies: *F. s. paulus*.

Appendix 14. Scientific and common names of plant species mentioned in the text.

Common Name	Scientific Name
basin big sagebrush	*Artemisia tridentata tridentata*
bearded bluebunch wheatgrass	*Agropyron spicatum*
big sagebrush	*Artemisia tridentata*
black greasewood	*Sarcobatus vermiculatus*
black sagebrush	*Artemisia nova*
Bolander silver sagebrush	*Artemisia cana bolanderi*
cleftleaf sagebrush	*Artemisia arbuscula arbuscula*
crested wheatgrass	*Agropyron desertorum*
curlleaf mountainmahogany	*Cercocarpus ledifolius ledifolius*
early low sagebrush	*Artemisia longiloba*
Idaho fescue	*Festuca idahoensis*
low sagebrush	*Artemisia arbuscula arbuscula*
mountain big sagebrush	*Artemisia tridentata vaseyana*
mountain silver sagebrush	*Artemisia cana viscidula*
mountain snowberry	*Symphoriocarpos oreophilus*
pinegrass	*Calamagrostis rubescens*
quaking aspen	*Populus tremuloides*
shadscale saltbush	*Atriplex confertifolia*
squaw apple	*Peraphyllum ramosissimum*
stiff sagebrush	*Artemisia rigida*
subalpine big sagebrush	*Artemisia tridentata spiciformis*
threetip sagebrush	*Artemisia tripartita*
western juniper	*Juniperus occidentalis*
Wyoming big sagebrush	*Artemisia tridentata wyomingensis*

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WILDLIFE HABITATS IN MANAGED RANGELANDS—THE GREAT BASIN OF SOUTHEASTERN OREGON

Technical Editors

JACK WARD THOMAS, U.S. Department of Agriculture, Forest Service

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Plant Succession Following Logging in the Sitka Spruce-Western Hemlock Forests of Southeast Alaska: Implications for Management

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Abstract

Alaback, Paul B. Secondary succession following logging in the Sitka spruce-western hemlock forests of southeast Alaska: Implications for wildlife management. Gen. Tech. Rep. PNW-173. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 26 p.

Preliminary information on general landscape patterns in southeast Alaska suggests that two major, compositionally distinct vegetation zones can be defined for the closed-forest type: western hemlock-Sitka spruce/Alaska huckleberry/bunchberry on the uplands, and Sitka spruce/devils club-salmonberry on alluvial flats and terraces.

Recent clearcuts (0 to 30 years old) produce the most shrubby vegetation of any age class in the forest succession. Even-aged forests (30 to 150 years old) produce the least understory vegetation. Uneven aged, old-growth forests sustain the most structurally diverse understory vegetation. Forests with open, patchy canopies tend to produce the most understory vegetation. More data is needed before forest management techniques can be successfully used to improve the quality of habitat for wildlife over that presently found in unmanaged old-growth forests.

Keywords: Succession (secondary), biomass, understory layer, logging effects, logging (-wildlife, old-growth stands, wildlife management, Alaska (southeast), western hemlock, Sitka spruce.

Summary

Preliminary information from several studies of vegetation dynamics in southeast Alaska suggests that silvicultural thinning may enhance understory productivity in young even-aged (<100-year-old) stands, yet there are no data at this time to suggest that silvicultural thinnings or timber rotations less than 200 years will measurably increase either the diversity or productivity of understory vegetation over that typically found in old-growth forests. Repeated thinnings may be necessary to maintain a high rate of understory productivity in second-growth stands. More data are needed before forest management techniques can be successful in improving the quality of habitat for wildlife over that presently found in unmanaged old-growth forests.

Increased understory growth tends to be associated with environmental factors that are related to decreased canopy density, low stocking, and reduced tree vigor. Thin, rocky soils and alluvial terraces tend to have the most productive understory vegetation and the least dense overstory canopy. Windthrown stands have highly variable understories, depending on the frequency and intensity of disturbance.

The same general pattern of successional development has been documented over a range of site conditions, although sites on alluvial flats or terraces dominated by Sitka spruce tend to develop a productive understory in the earliest stages of stand development and have a rate of successional development more variable than most upland sites. Prior to closure of the overstory canopy, stands with high site indices (>120) have significantly greater understory productivity than stands with low site indices (<110). Site index is not significantly related to understory productivity over the range of post-canopy closure sites that have been sampled.

To evaluate long-term management alternatives, we need to better define the relationships of site conditions, forest canopy structure and understory growth so that more realistic predictions of understory responses to management can b made. Changes in forest nutrient cycling, snow interception, and overall microclimate that result from management have yet to be studied in southeast Alaska. The value of intensively managed forests to wildlife throughout a forest rotation remains a key topic for future research.

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Introduction

Populations of wildlife in Alaska are often limited by the availability of suitable habitat (Klein 1965, Van Horn 1981, 1982, Wallmo and Schoen 1980, Wolff 1980). The relationship of habitat to animal density has been the focus of numerous studies in wildlife ecology but is still poorly understood.

Wildlife habitat has three basic components: forage, cover, and microclimate. Each species of wildlife has requirements that vary with genetic and behavioral plasticity, time of day, season of year, competition, and climate. Habitat requirements may also vary with geographic location. The value of specific sites also depends on the interactions of snow accumulation, habitat diversity, travel corridors, predators, and diseases.

The availability of nutritious understory herbs and shrubs, in snow-free environments, is generally considered the key habitat factor that limits Sitka black-tailed deer in Alaska (Bloom 1978, Schoen and Wallmo 1979, Wallmo and Schoen 1980). For forest bird populations, the abundance of understory plant species and their vertical stratification and diversity are key habitat factors in Alaska and the Pacific Northwest[1] (Meslow 1978, Meslow and others 1981). Changes in populations of mammals have also been related to changes in understory structure (Harris and others 1982, Van Horn 1981, 1982).

In view of the importance of understory vegetation to many wildlife species, the response of understory vegetation to management should be a key factor in management decisions. To evaluate the potential of forest sites for wildlife habitat it is necessary to predict the response of understory plant species to natural and human-caused disturbances. The accuracy of predicting management impacts on wildlife populations is limited by a lack of information on both the habitat requirements of wildlife species and the response of vegetation to perturbation.

This study had three primary objectives:

1. To summarize knowledge about the response of forest vegetation to natural and human disturbance in the Sitka spruce-western hemlock forests of southeast Alaska.

2. To illustrate how site characteristics and management activities affect the productivity and composition of understory vegetation.

3. To outline research needs and directions on the relationship of stand characteristics to understory vegetation growth and abundance.

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[1] Kessler, Winifred, B. Bird population responses to clearcutting in the Tongass National Forest of southeast Alaska. Juneau, AK: U.S. Department of Agriculture, Forest Service, Alaska Region; 1979; Rep. 71. 22 p.

Forest Plant Communities of Southeast Alaska

The response of understory vegetation to disturbance varies with the environmental characteristics and history of sites. Environmental characteristics are reflected by the plant community that characterized the site before disturbance. A statewide hierarchical vegetation classification has been proposed to define these plant communities for Alaska (Viereck and Dyrness 1980). This classification is most nearly complete for interior and northern Alaska. Detailed information on plant community patterns in southeastern Alaska is lacking. Vegetation studies in southeast Alaska have focused on broad landscape patterns and corresponding environmental gradients. The transition between muskeg and the forest vegetation in southeast Alaska was the subject of one major study, but it did not include data relevant to development of a community classification (Neiland 1971). A life-form classification for the vegetation of the Glacier Bay area was the subject of another study, but it did not include information on specific plant communities within each of the physiognomic vegetation units (forest, subforest, spruce parkland, deciduous shrublands).[2]

A classification system has been developed for southeast Alaska which divides forested land into classes based on soil morphology.[3] The classification was designed to relate soil types to forest productivity classes (site index of dominant Sitka spruce at 100 years of age). Although the classification relates well to broad site-productivity classes, each type encompasses a broad range of forest types (and site indexes) and is not closely related to plant communities.

The only vegetation-based land classification that has been proposed for southeast Alaska is a broad-based, zone-level classification.[4] As with the soils classification, this scheme is insufficient for stratifying the response of vegetation to disturbance. Two forest community types, for example, cover most of the commercial forest land on the Tongass National Forest: Sitka spruce and western hemlock-Sitka spruce (table 1).

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[2] Worley, I. A. Plant community analysis. In: Dixon Harbor Biological Survey, Final Report on the summer phase of 1975 research. Juneau, AK: U.S. Department of the Interior, Park Service; 1977; p. 126-239.

[3] Stephens, F. R.; Gass, C. R.; Billings, R. F.; Paulson, D. E. Soils and site index in southeast Alaska. Juneau, AK: U.S. Department of Agriculture, Forest Service, Alaska Region. 1969. 67 p.

[4] Alaback, Paul B. Provisional plant community types of southeastern Alaska. Fairbanks, AK: U.S. Department of Agriculture, Forest Service, Institute of Northern Forestry. 1979.

Table 1—Closed forest types of southeast Alaska[1]

Type	General location
Closed conifer forest:	
1. Sitka spruce	Alluvial floodplains or terraces and shorelines
2. Sitka spruce-western hemlock	Extensive below 1500 feet; transition between types 1 and 3
3. Western hemlock-Sitka spruce	Extensive below 1500 feet; more widespread than type 2
4. Western hemlock-western redcedar	South of Frederick Strait; on average to poorly drained sites
5. Pacific silver fir	Localized east and south of Ketchikan; on well drained slopes protected from salt spray; below 2000 feet
6. Mountain hemlock	Near timberline, generally above 1500 to 2000 feet; where winter snowpack persists and saturated organic soils occur
7. Mountain hemlock-western hemlock	Transition to mountain hemlock from type 3; 0 to 2500 feet but generally above 1000 feet, with a longer snowpack than type 3
8. Subalpine fir	Isolated pockets on Prince of Wales and Kosciusko Islands and other locales; associated with mountain and western hemlock
Closed hardwood forest:	
11. Red alder	Riparian, often on wet and disturbed sites; generally below 2000 feet; seral to types 1 through 4
12. Black cottonwood	Recently deglaciated terrain with thin, rocky soils; also on and along streams; seral to types 1 through 4

[1] Adapted from Viereck and Dyrness 1980.

Forest Development Following Disturbance

Ecologists initially conceptualized plant succession as a unidirectional progression of plant species that results in a "climax" or self-perpetuating community. Studies of forest succession have consistently indicated that the process is far more complex. In their review of more than 100 years of the world literature on plant succession, Drury and Nisbet (1971) conclude that initial conditions, combined with disturbance during the successional sequence, exert a major influence on patterns of forest development. In southeast Alaska the type and intensity of disturbance also plays an important role in determining the course of plant successional development.

Primary Succession

Plant succession that involves colonization of rock or soil that has been completely denuded of vegetation is generally referred to as "primary succession" (Whittaker 1975). Under the austere microclimatic conditions characteristic of seedbeds that undergo primary succession, forest development proceeds slowly and involves many stages, as defined by changes in dominant plant species. Shallow soils, low in moisture-holding capacity and suboptimal in nutrient availability are the most likely cause of slow and variable vegetative response during primary succession[5] (Crocker and Major 1955).

Primary succession has been studied in Alaska for more than five decades. Plant succession at Glacier Bay following deglaciation has been documented by information on glacial retreat and remeasurement of a series of permanent plots (Cooper 1923, 1939, Lawrence 1958, Reiners and others 1971). Four general stages of plant community development are recognized: (1) pioneer, (2) willow-alder, (3) spruce forest, and (4) climax spruce-hemlock (Cooper 1923, Reiners and others 1971).

The most variable rate of plant colonization and growth occurs in the pioneer stage of primary succession, in which mosses and lichens (such as *Rhacomitrium* and *Stereocaulon*)[6] are the most common species. As soil development proceeds, herbs adapted to disturbed areas, such as fireweed, *Dryas*, and horsetail begin to colonize. Prostrate shrubs such as willow and bearberry may also occur during this stage.

The willow-alder stage is characterized by the dominance of woody shrubs and tree saplings. Sitka alder, black cottonwood, Sitka willow, and Alaska willow are the most common species during this stage. Sitka spruce colonizes the thickets, eventually forming a continuous canopy over the shrubs and giving rise to the third stage of the succession (Cooper 1923).

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[5] Ugolini, F. C. Soils. In: Soil development and ecological succession in a deglaciated area of Muir Inlet, southeast Alaska. Rep. 20. Columbus, OH: Ohio State University Institute of Polar Studies. 1966: 29-72.

[6] Scientific and common names of plants are listed in the appendix.

Invasion by western hemlock and the development of a dynamic equilibrium of tree growth and decay lead to the final climax stage. Western hemlock is generally dominant in both overstory and understory and maintains dominance unless large gaps in the canopy are created by windthrow, fire, or disease. When such gaps are formed, Sitka spruce, red alder, and other species less tolerant of shade may colonize the site. Despite the youthfulness of these soils, the species composition and vegetation structure of climax forests are usually comparable to those of forests growing on older soils (Lawrence 1958, Reiners and others 1971).

The development of forest vegetation following landslides or mudflows—a type of primary succession important to forest management—remains largely unstudied in southeast Alaska. Physical factors relating to the incidence and form of mass wasting have been the subject of more than two decades of research (Bishop and Stevens 1964, Swanston 1970, Swanston and Swanson 1976). But additional information is needed on plant colonization of landslides under differing microclimatic and edaphic conditions before we can predict the course and timing of forest development.

Secondary Succession

Plant succession following a disturbance that does not entirely eliminate the original vegetation is termed "secondary succession" (Whittaker 1975). Most forest management activities in southeast Alaska involve sites undergoing secondary succession.

After a site is clearcut, vegetation develops in predictable stages, defined by plant community composition and structure (Alaback 1982a, 1982b, Harris and Farr 1974, Taylor 1932a). At any stage, species composition may differ according to environmental characteristics peculiar to the site, but the overall pattern of understory productivity over time is similar for all sites studied in the region (fig. 1).

Seedling-sapling and understory colonization stage: 1 to 25 years.—Within three growing seasons after a site has been logged, shrubs such as Alaska blueberry and red huckleberry vigorously sprout from underground stems or establish new seedlings and dramatically increase in productivity over growth sustained in undisturbed old-growth forests (fig. 1). The quickest response of understory shrubs to logging is in alluvial river bottoms or old terrace sites (Alaback 1980, Harris and Farr 1974). Herbs, such as bunchberry, and ferns, such as oakfern and spreading wood fern, also rapidly colonize logging sites but usually accumulate less biomass than woody shrubs (Alaback 1980) (table 2, fig. 2). Extensive soil disturbance caused by logging on moist sites often encourages colonization by shrubs such as salmonberry, trailing black currant, and red alder. Lady fern, spreading wood fern, and bunchberry tend to dominate moist microsites and areas where tree and shrub regeneration is sparse. It is during this stage that most of the colonizing tree and shrub seedlings become established.

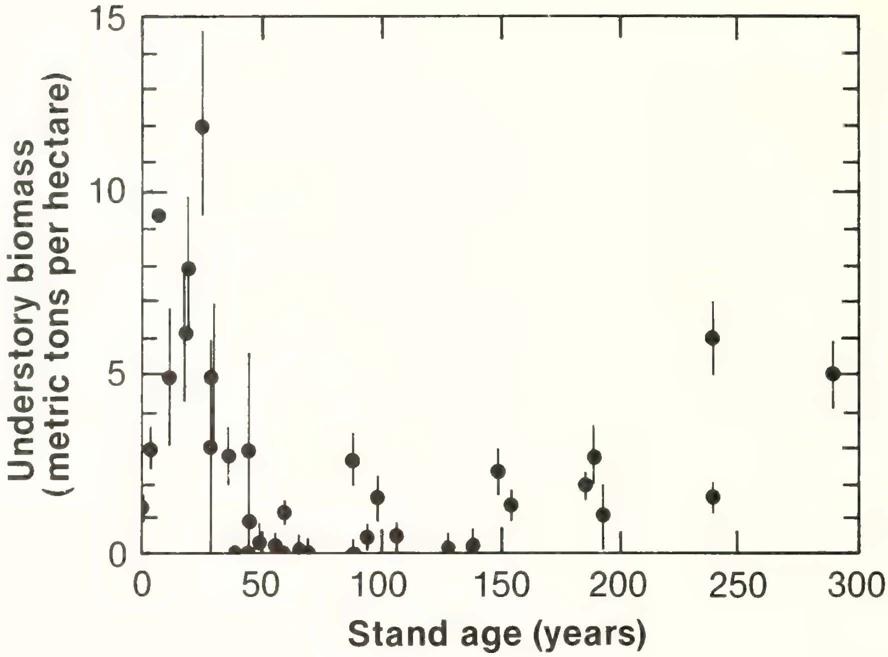

Figure 1.—Accumulation of understory biomass following disturbance in southeast Alaska. Bars represent 95-percent confidence limits on estimates of mean biomass accumulation for each site (adapted from Alaback 1982b)

Table 2—Tree seedling and shrub biomass in 4 forest types in southeast Alaska[1]

	Forest type[2]			
Species	Clearcut	Dense, even-aged	Mature, even-aged	Old-growth
	Kilograms per hectare			
Shrubs:				
Rusty menziesia	125.7	4.7	27.4	36.5
Devils club	0	.1	5.4	3.3
Trailing currant	14.7	1.7	0	.2
Salmonberry	1,031.0	11.5	1.9	48.5
Alaska blueberry	829.3	16.4	69.2	378.0
Red huckleberry	170.7	19.6	52.8	24.0
Tree seedlings:				
Sitka spruce	1,574.3	16.7	2.8	10.2
Western redcedar	90.0	7.6	0	.1
Western hemlock	6,042.3	64.9	133.2	822.5

[1] Adapted from Alaback 1982b. Seedlings are trees with diameter at breast height less than 1 inch.

[2] Clearcuts include sites logged 0-30 years ago; dense, even-aged sites are 30-100 years old; mature, even-aged sites are 100-250 years old; and old-growth sites are more than 250 years old.

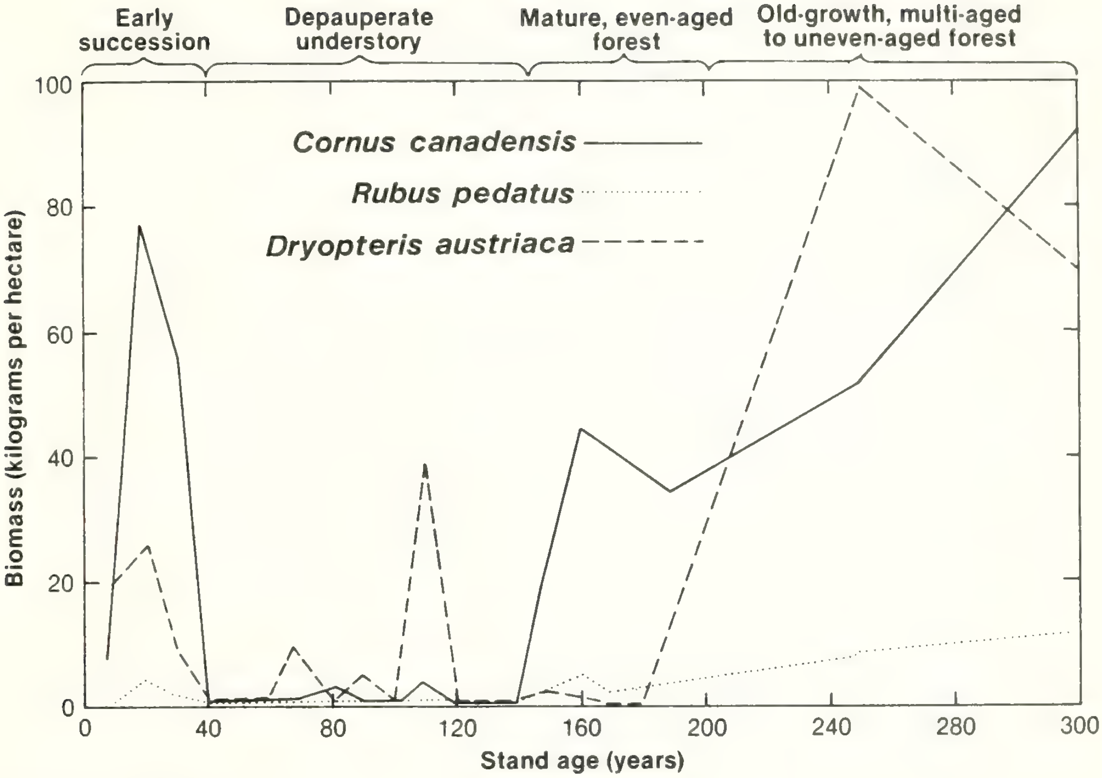

Figure 2.—Biomass accumulation of three common herbaceous species during stages of secondary succession in southeast Alaska (adapted from Alaback 1982a).

Dense, closed-forest and understory-exclusion stage: 26 to 150 years.—Canopy closure decreases the amount of light that reaches the forest floor and is associated with a rapid reduction in understory biomass (fig. 1). Low, herbaceous vegetation is usually less than one percent of the biomass it attains in the seedling-sapling stage (Alaback 1980).

Alaska blueberry is generally restricted to gaps in the canopy or other areas where direct sunlight reaches the understory. Semi-parasitic plants, such as single delight, and achlorophyllous plants, such as coralroot, are often the only herbaceous, flowering plants that persist. This stage has been termed the "stem exclusion stage" because few shrubs or tree seedlings can successfully colonize (Oliver 1981).

The dense, closed-forest stage includes pole-sized timber on overstocked sites or lower site class, normally stocked lands (site index less than 80) and young sawtimber on medium- to high-site lands (site index 90 and above; Taylor 1934). On understocked, poorly drained sites (F5 ecosystems; see footnote 3) the understory exclusion stage is least pronounced, because a continuous dense overstory canopy may be lacking or sustained for a shorter period than on well drained sites (Alaback 1980).

Mature, even-aged forest and understory-reinitiation stage: 150 to 250 years.—As even-aged forests reach stand age 150 to 200, shrub seedlings begin to recolonize the understory (Alaback 1982b). Alaska blueberry usually forms a low, highly branched layer in older, even-aged forests. Five-leaf bramble and other herbs may also be found scattered within these stands (Alaback 1980). The establishment of a productive understory is generally associated with a decline in moss and liverwort biomass, which probably improves seedbed conditions for further understory colonization (Minore 1972, Taylor 1935).

The mature, even-aged forest stage represents the peak in gross standing timber volume of the successional sequence (Alaback 1980, 1982a). Toward the end of this phase, wood decay and defect become more significant (Farr and others 1976) and the rate of woody biomass accumulation steadily declines (Alaback 1982a). These changes in the dynamics of the overstory are usually reflected in a more open overstory canopy. The transition from the stage of dense, closed forest and understory exclusion to the stage of mature, even-aged understory reinitiation is usually characterized by the opening and vertical stratification of the overstory canopy (Alaback 1982b, 1984, Franklin and others 1981).

Old-growth stage: 250 years and older.—The highest degree of variation and the most structurally diverse understory of any successional stage is found in old-growth forests. Patches of shrubs, tree saplings, and herbs alternate with patches dominated by moss and duff or ferns, making a complex, multilayered mosaic. The highest dominance by shrubby understory species and the highest frequency of herbs occur on understocked, poorly drained sites (Neiland 1971). In contrast, well-drained, well-stocked sites have less understory (Alaback 1980, 1982b). This pattern of understory growth in relation to site conditions reflects differences in overstory canopy structure. Stands with widely spaced trees and complex, multilayered canopies, allow more light, highly variable in intensity, to reach the forest floor than do stands with several canopy strata of dense western hemlock or western red cedar pole-sized trees (Alaback 1980, Logan and Peterson 1964).

The amount of understory vegetation varies considerably in old-growth forests. In many stands, there are pockets of trees less than 150 years old, under which shrubby or herbaceous understory is deficient. In open portions dominated by trees more than 250 years old, there is often a shrub stratum composed of red huckleberry, Alaska blueberry, and rusty menziesia[7] (Alaback 1982a; also see footnote 1).

Although woody shrubs dominate, old-growth forests have the greatest proportion of understory production contributed by herbs and low shrubs of any successional stage (Alaback 1982b, 1984) (fig. 3). Bunchberry, five-leaf bramble, fernleaf goldthread, and foamflower are particularly abundant (Alaback 1982a). At elevations less than 500 feet these herbs may be the most nutritious available forage for deer during the winter months (Schoen and Wallmo 1979).

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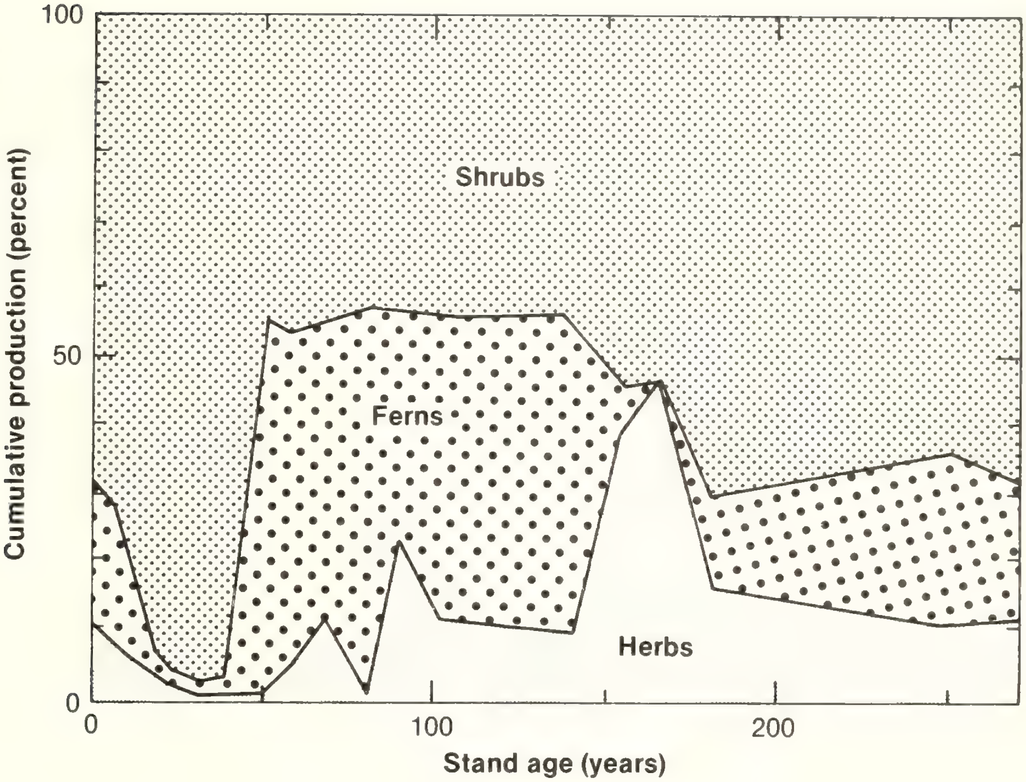
[7] Noble, R. E. Breeding bird populations in hemlock-spruce old-growth and clearcuts, Prince of Wales Island, Alaska. Ketchikan, AK: U.S. Department of Agriculture, Forest Service, Tongass National Forest, Ketchikan Area; 1979. 65 p.

Figure 3.—Changes in understory production during secondary succession in southeast Alaska (adapted from Alaback 1982b).



Understory compositional changes during successional development.—The herbaceous and shrubby vegetation of Sitka spruce-western hemlock forests of southeast Alaska is composed primarily of 20 to 30 species (table 3). In the 60 sites studied by Alaback (1980) 70 percent of the ground cover was provided by the 10 most abundant species, each of which was found on 90 percent or more of the sites. Subtle changes in the dominance of these plants can be significant both to wildlife and the course of plant succession.

Variations in the relative dominance of understory plants are associated with differing degrees of overstory canopy disturbance, disruption of the soil mantle, and site characteristics such as soil drainage, nutrient availability, and microclimate (Alaback 1980; also see footnote 4). If bare mineral soil is exposed and much of the organic layer is lost, early successional or even primary successional species will colonize the site. Early colonizers include horsetail, *Dryas*, lichens, mosses, and deciduous trees such as Sitka alder, red alder, black cottonwood, and willow species (Cooper 1923).

The most fundamental change in composition during post-logging succession is the elimination of most shrub and herb species during the period after canopies close and before they open again at stand age 150 to 200. During the later part of the depauperate-understory phase, a fern-dominated understory may form a compositionally distinct subphase in the succession (fig. 3).

Table 3—Relative abundance of understory plants on 60 study plots located throughout southeast Alaska[1]

Class and species	Cover[2]	Production[2]	Cover rank[3]	Constancy[4]
		Percent		
Bryophytes and lichens:				
Cladonia conioceraea	0.5	+	33	41
Dicranum fuscescens	1.8	.8	10	94
Foliose Lichens[5]	.8	+	26	77
Hookeria lucens	.2	+	40	26
Hylocomium splendens	11.4	7.7	2	97
Isothecium stoloniferum	.6	+	31	62
Jungermanniales spp.	3.3	.5	7	86
Marchantia polymorpha[6]	.6	.3	32	30
Plagiothecium undulatum	3.7	.6	5	97
Pogonatum macounii	.7	.1	27	68
Polytrichum spp.[7]	.5	+	34	44
Porella navicularis	1.8	+	13	86
Ptilium crista-castrensis	.9	.3	23	41
Rhizomnium glabrescens	7.0	2.8	4	92
Rhytidiadelphus Loreus	25.0	11.2	1	96
Sphagnum spp.[8]	1.6	1.2	14	61
Timmia austriaca	.2	+	41	23
Other mosses[9]	1.6	.5	15	70
Conifers:				
Picea sitchensis	.9	3.3	22	47
Thuja plicata	.2	.5	42	11
Tsuga heterophylla	2.9	18.0	9	89
Ferns:				
Athyrium felix-femina	1.2	.3	19	38
Blechnum spicant	.6	.1	29	26
Dryopteris austriaca	3.6	.8	6	85
Gymnocarpium dryopteris	3.0	.2	8	71
Lycopodium annotinum	.1	+	47	11
Thelypteris phaegopteris	.1	+	46	6
Shrubby flowering plants:				
Gaultheria shallon	.2	+	43	9
Menziesia ferroginea	.1	.8	21	55
Oplopanex horridum	.9	+	25	29
Ribes laxiflorum	.3	+	47	6
Rubus spectabilis	2.6	19.1	10	39
Sambucus canadensis	.1	+	45	11
Vaccinium alaskaense	8.4	5.0	3	88
Vaccinium parvifolium	1.2	1.9	20	91

See footnotes at end of table.

Table 3—Relative abundance of understory plants on 60 study plots located throughout southeast Alaska[1]—continued

Class and species	Cover[2]	Production[2]	Cover rank[3]	Constancy[4]
		Percent		
Herbaceous flowering plants:				
Coptis asplenifolias	.9	+	24	38
Cornus canadensis	1.5	.5	16	61
Maianthemum dilatatum	.7	.1	28	46
Moneses uniflora	.6	+	30	61
Rubus pedatus	2.0	+	11	59
Streptopus amplexifolius	.4	+	36	30
S. roseus	.3	+	37	30
S. streptopodes	.5	.2	22	47
Tiarella trifoliata	.2	+	18	70
Viola glabella	.1	+	44	12

+ indicates <0.1 percent production.

[1] Source: Alaback 1982b.

[2] Mean percent of total vegetation.

[3] Rank from highest (1) to lowest (57) in percent ground cover.

[4] Percent of study sites for which the species was recorded.

[5] Primarily *Lobaria oregona* and *Peltigera canina*; Also *Sphaerophorus bulbosus* and *Hypnogymnia enteromorpha*.

[6] Also includes *Conocephalum commune.*

[7] *P. juniperinum* and *P. commune.*

[8] *S. squarrosus* and *S. girgensohnii.*

[9] *Plagiothecium elegans, Ptilium crista-castrensis,* and *Hypnum* spp.

Herbaceous annuals are less important in early succession in southeast Alaska than they are in other forest regions (Alaback 1982a, Hill 1979, Dyrness 1973, Kellman 1969, Long and Turner 1975). On sites with less soil disturbance from logging operations, Alaska blueberry and bunchberry are usually the most abundant. Salmonberry and trailing black currant are prolific on recently disturbed sites, particularly on alluvial river bottoms or terraces (Alaback 1980). Herbaceous colonizing plants (as opposed to resprouting woody residuals) are usually most abundant in sites that have been burned after logging (Dyrness 1973, Kellman 1969). Preliminary evidence also suggests that fire may encourage the colonization of herbaceous species in southeast Alaska.

The response of plant species to disturbance of varying severity can be predicted by ranking plants in order of shade tolerance. Percent of ground covered by vegetation under gaps in the canopy and under closed canopies can be used to define patterns of shade tolerance for these species (table 4). On this basis, salmonberry is the most intolerant of shade, followed, in order, by bunchberry, fernleaf goldthread, Alaska blueberry, red huckleberry, five-leaf bramble, spreading wood fern and oakfern. Preliminary evidence suggests that oval-leaf huckleberry may be less shade-tolerant than Alaska huckleberry, because it is distributed in more open areas (Neiland 1971).

Species with the least shade tolerance, such as salmonberry, are more abundant on heavily disturbed sites where little forest canopy persists. Shade-tolerant species such as five-leaf bramble or fernleaf goldthread are more abundant in forests that have undergone the least amount of disturbance.

Little is known about the autecological requirements of the principal herbs and shrubs that colonize Sitka spruce-western hemlock forests. In Oregon and British Columbia, where similar species occur, distinct patterns of change in species composition have been documented in relation to microenvironment, forest productivity, soil morphology, and disturbance (Dyrness 1973, Kellman 1969, Zobel and others 1976).

The patterns of species abundance across environmental gradients are complex, partly because the growing season is mild and many understory species are able to grow in the widely contrasting ecosystems of bogs, forests, and alpine meadows (Jacques 1973, Neiland 1971; also see footnote 2). As a consequence, the presence or absence of a particular species often has little relation to microenvironment or site fertility. The presence or absence of some species, especially those with little annual seed production, may be limited by the efficiency of their propagule-dispersing mechanisms as well as their growth requirements.

Only two forest zones can be defined on the basis of species composition in the zonal vegetation classification for southeast Alaska (Viereck and Dyrness 1980; also see footnote 4). These are (1) Sitka spruce and (2) Western hemlock-Sitka spruce. On fertile, wet alluvial, or bench sites of the Sitka spruce type, the understory usually includes foamflower, salmonberry, and devils club. Most upland forests are included in the western hemlock-Sitka spruce community and are characterized by poorly drained, lower tree-site indices and understories dominated by Alaska blueberry, five-leaf bramble and bunchberry[8] (Taylor 1932b). This gradient in site conditions is often poorly displayed by changes in understory composition caused by localized conditions and differing disturbance regimes (Alaback 1982b).

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[8] Schoen, John W.; Kirchoff, Matthew D.; Wallmo, O. C. VII Progress Report, Federal Aid in Wildlife Research, Project W-21-1. Seasonal distribution and habitat use by Sitka black-tailed deer in southeastern Alaska. Juneau, AK: Alaska Department of Fish and Game; 1981.

Table 4—Proportion of understory vegetation under canopy and under gaps in canopy in southeast Alaska[1]

Species	Mean average cover[2]				Proportion under gaps
	Under gaps[3]		Under canopy		
	Percent	*Standard error*	*Percent*	*Standard error*	*Percent*
Shrubs:					
Salmonberry	2.5	0.37	0	0	100.0
Alaska blueberry	8.5	1.35	3.6	.49	70.2
Red huckleberry	.4	.06	.20	.06	64.3
Total shrubs	11.39		3.8**		75.0
Herbs:					
Fern-leaf goldthread	1.16	.15	.43	.12*	73.0
Bunchberry	11.30	.35	.87	.28**	93.0
Spreading wood fern	3.71	.35	3.10	.78	54.5
Oakfern	2.70	.31	3.10	.80	46.6
Five-leaf bramble	2.42	.23	1.58	.37	60.5
Total herbs	21.29		9.08**		70.1

*Significantly different at P=0.95.

**Significantly different at P=0.99.

[1] Adapted from Alaback 1982a.

[2] Percent cover is the arithmetic mean for all microplots under gaps or under closed canopy.

[3] Subplots with less than 80-percent tree canopy cover in any quadrant.

Effects of Stand Disturbance on Understory

The frequency and intensity of disturbance of the forest canopy has an important influence on the productivity of understory vegetation. Stands of seedlings or saplings are most resilient to disturbance (Alaback 1980). Virtually any kind of disturbance will result in a prompt increase in shrub and herb production. Understory shrubs and herbs in dense, closed stands of poles or young sawtimber respond much less vigorously to disturbance than those in stands of seedlings or saplings.

When pole or sawtimber stands are subject to localized windthrow, and less than 40 percent of the canopy is destroyed, the increased growth of seedlings or saplings often results in the prompt reestablishment of a dense canopy. The resulting, multi-layered stand tends to have much less herbaceous and shrubby understory than undisturbed stands (Alaback 1980). Windthrow over more than one acre leads to a dramatic increase in understory productivity, setting portions of the stand back to earlier stages of succession (Alaback 1980, Whitmore 1982) (table

The type of disturbance and the environmental characteristics of the site immediately following the disturbance, may significantly influence the pattern and cours of forest development for decades (table 5). For example, a stand that develops following windthrow differs substantially from a stand that develops after logging Following windthrow, overstory biomass accumulates more slowly, while levels o understory biomass are higher (Alaback 1982a). Large numbers of slowly decaying logs, which often characterize stands that develop in the wake of destruction by windthrow, may inhibit tree regeneration and lead to patchy, open canopies. Windthrow usually causes less disturbance to understory plants than logging anc favors the growth of residual understory species such as Alaska blueberry and spreading wood fern (Alaback 1980).

Table 5—Time required for plant succession following disturbance in southeast Alaska, under average site conditions[1]

Disturbance type	Shrub colonization	Tree colonization	Spruce dominance
	Years	*Years*	*Percent of basal area*
Glaciation or landslides	>10	>10	>50
Logging, infrequent	<2	<5	20-50
Windthrow, frequent	<1	<1	<10
Windthrow, (<1 acre)	NA	<1	<1

NA means not available.

[1] Does not include forest developing on alluvial-terrace or uplifted beach soils.

Relationships Between Forest Structure and Understory Development

In the natural pattern of post-logging succession, understory vegetation is eliminated for 60 to 70 years in stands with average to above average stocking (Taylor 1934). To find how the course of successional development can be altered to encourage the growth of understory vegetation over a longer period it is necessary to first understand the relationship between stand structure and understory growth.

The biomass of mosses, liverworts, and ferns is usually greatest on sites with heavy log cover and a closed overstory canopy. Variation in moss and liverwort biomass in second-growth stands is not clearly related to stand age, stand basal area, stand volume, or canopy cover as herb and shrub biomass are (Alaback 1980).

Shrub biomass is greater in second-growth stands with open overstory canopies, low tree-foliage biomass, low basal area, low stocking, and low tree volume. Herbaceous plants tend to be most productive in young clearcuts (3 to 15 years) prior to canopy closure (Alaback 1980, 1982a).

In old-growth and mature stands with average to above average stocking (30,000 to 100,000 board feet per acre), the relationship of understory strata to stand characteristics is fundamentally different (Alaback 1980). Shrubs are most abundant in old-growth stands with large mean diameters. Herb abundance on the more productive sites (F1 and F4 soil ecosystems; see footnote 3) is also strongly associated with large tree diameters, high stand volume, wide tree spacings and low tree density (Alaback 1982b). On sites that are understocked (less than 70 percent of normal), windthrown, or poorly drained, tree density is inversely proportional to abundance of understory (Alaback 1980, Neiland 1971).

In older stands, percent canopy cover does not have a significant relationship to understory abundance. This is most likely because of the difficulty in precisely measuring percent canopy cover in multilayered old-growth forests. In the deep, shade-tolerant canopies of western hemlock, relationships between light interception and canopy cover are highly variable. Multiple regression analysis showed that 79 percent of the variation in total understory production in mature and old-growth stands can be accounted for by stand age (average age of codominant overstory trees), mean stand diameter, and volume (Alaback 1982b). Thus for the stands sampled (30,000 to 100,000 board feet per acre) these three variables can be used to make reasonable predictions of understory productivity.

The change in structure from the dense, uniform canopies of even-aged, second-growth forest to the open canopies of uneven-aged, old-growth forests changes the understory environment by increasing the amount of canopy light and reducing rainfall interception (Anderson and others 1969, Franklin and others 1981, Pike and others 1977). Measures of canopy cover are not sufficiently precise to detect the subtleties of canopy structure. When precise and detailed data on overstory structure and the amounts of light they intercept become available, questions on overstory-understory interactions can be answered more fully.

Effects of Stocking and Site on Forest Succession

While the above-mentioned forest development pattern may apply generally to the low-elevation, well-drained sites most commonly managed for timber production, variations on the pattern and their causes are also of interest to forest and wildlife managers. In general, the more productive and well stocked the rotation-aged forest is, the less likely it is to support a high level of diverse and productive understory vegetation (Alaback 1982b).

The relationship of site quality to the course of plant succession is complex, often resulting in a different response for each developmental stage. Site index, for example, is not linearly related to the amount of understory biomass on a given site over the successional sequence. Prior to canopy closure, site index is positively related to understory productivity. After canopy closure, differences in productivity of the understory on different site classes are not statistically significant (table 6).

A high-site stand (site index greater than 150) usually regenerates quickly, allowing for more rapid establishment of dominance among seedlings than on an average site of the same age. Thus on highly productive sites canopies usually close earlier than on sites with average productivity, and understory vegetation is eliminated. Later in the developmental sequence, the forest canopy develops more quickly in high-site stands, resulting in fewer trees and a more open canopy.

Table 6—Relationship between site index and understory productivity during the first 2 phases of postlogging succession

Successional phase and site index class[1]	Understory biomass	Standard error
	Kilograms/hectare	
Early postlogging succession (precanopy closure):		
100-110	4 400	1 700
111-120	12 000	—
121-130	21 000	11 000
Mature, even-aged forests (postcanopy closure):		
60-100	347	102
101-120	234	56
121-130	171	54
131-150	546	225

— Means not available.

[1] Site index is based on the mean height of dominant Sitka spruce 100 years old (Taylor 1934).

As a result, levels of understory biomass may be higher in high-site stands (site index exceeding 150) than is typical of sites with average productivity (site index 100 to 130) (Alaback 1980; also see table 6).

Tree density is usually related to the time understory vegetation requires to recolonize following canopy closure. Stands with high stocking (greater than that given by Taylor 1934) often lack measureable understory vegetation (less than 100 kilograms production per hectare). On the Chilcat Peninsula, a densely stocked stand (622 trees per acre, 150 years old), lacked any evidence of understory recolonization, even though most stands of this age have a well developed understory (Alaback 1980, 1982b). On steep, rocky slopes where stands are often subject to windthrow and may attain less than 80 percent of normal stocking (Taylor 1934) shrubby and herbaceous vegetation may persist throughout the successional sequence. The open canopy, characteristic of understocked stands (less than 80 percent of normal), is usually associated with more understory vegetation.

At higher elevations, especially on steep, unstable slopes where widely spaced, large diameter, residual trees provide an open patchy overstory canopy, a more productive and diverse understory tends to develop. In general the higher the elevation, and the less productive and more open the canopy, the more abundant the understory.

Effects of Thinning on Understory Vegetation

The Alaska Region of the Forest Service cites thinning as one of the most promising management tools for improving rotation-aged forests as wildlife habitat.[9] [10] No comprehensive studies of understory response to thinning in southeast Alaska have been completed. The only available data are from a case study of a 20-year-old stand on Prince of Wales Island (Tongass National Forest) (Alaback 1980), where, four years after thinning, a strong, positive response by shrubs and some herbs was noted. In an intensively thinned stand (16-foot spacing) salmonberry dominated the site, to the exclusion of most other species. The lightest level of thinning (12-foot spacing) resulted in the most diverse vegetation (fig. 4).

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[9] USDA Forest Service, Alaska Region. Alaska regional plan. Juneau, AK: U.S. Department of Agriculture; 1981.

[10] Kessler, Winifred, B. Wildlife and second-growth forests of southeast Alaska: Problems and potential for management. Administration Document 110, Wildlife and Fisheries Habitat Management Notes 4. U.S. Department of Agriculture, Forest Service, Alaska Region; 1982.

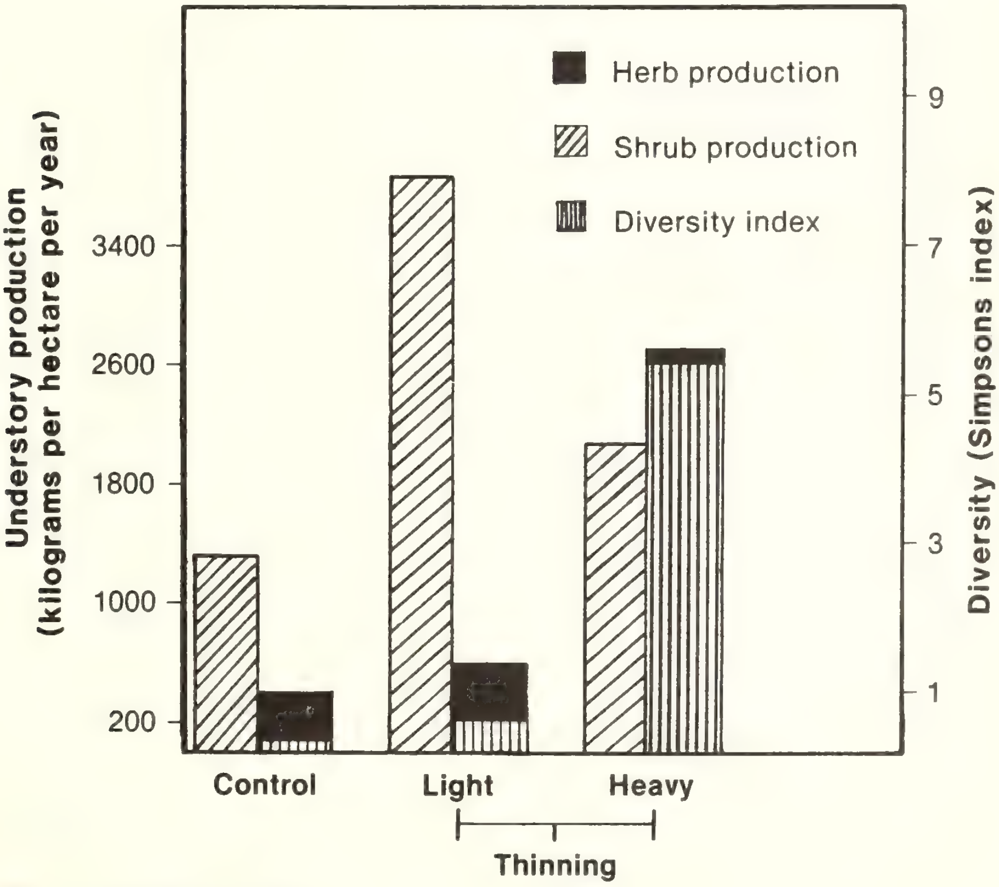

Figure 4.—Response of understory productivity to thinning in a 20-year-old stand. Diversity index is that developed by Simpson (1949).

Preliminary results of thinning experiments on other plots established throughout southeast Alaska[11] suggest that the response of understory vegetation to thinning following canopy closure at 25 to 35 years is much slower than in forests thinned prior to canopy closure. In general, stands that were thinned following canopy closure and elimination of understory vegetation have few shrub or herb species in the understory 5 years after thinning. At the widest spacings (16 feet for younger sites, 20 feet or more for the oldest sites) the principal understory species that respond to thinning are western hemlock and Alaska blueberry.[12] In heavily thinned stands opened up by subsequent windthrow—which is especially common in the older stand-age classes—western hemlock is the principal understory species to respond.

To objectively assess the effects of thinning on understory development, it is necessary to predict not only the short-term response but also the growth of understory plants over an entire rotation. At Cascade Head Experimental Forest in the Siuslaw National Forest on the Oregon coast, a series of Sitka spruce-western hemlock plots thinned 20 years ago provide one of the few opportunities to observe the longer term effects of precommercial thinning on understory vegetation. The greatest number of understory species was found on heavily thinned plots, yet none of the treatments had the continuous understory layer so characteristic of surrounding old-growth forests (see footnote 12). Under such conditions, the beneficial effects of thinning on understory growth would not be expected to last more than 20 years.

A one-time precommercial thinning only delays canopy closure and extends the period of understory persistence. Thinning alone would have little effect on understory growth during the latter half of a 100-year rotation (table 7). Repeated thinnings throughout the life of a stand may be necessary to maintain a highly productive understory (Witler 1975). The nutritive value to wildlife of an understory maintained by thinning remains a key topic for research.

[11] Farr, Wilbur A. Revised study plan. The effects of stand density upon growth and yield of hemlock-spruce stands in coastal Alaska. Juneau, AK: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, 1976; 24 p.

[12] Alaback, Paul A. Unpublished data on file at Forest Science Department, Oregon State University, Corvallis, Oregon.

Table 7—Management strategies and hypothesized time stands would be in 3 classes of understory productivity over 3 centuries of stand development

Strategy	Productivity class[1] Low	Medium	High	Period of medium or high productivity
		Years		
100-year rotation	210	0	90	90
100-year rotation with precommercial thinning[2]	180	0	120	120
300-year rotation	120	150	30	180
Old-growth reserve	0	300	0	300

[1] Low = 1 to 100 kilograms/hectare; medium = 100 to 1,000 kilograms/hectare; high = more than 1,000 kilograms/hectare.

[2] Assuming thinning delays canopy closure for 10 years.

Management Implications

Maintaining diverse and productive understory vegetation in the Sitka spruce-western hemlock forests of southeast Alaska requires the consideration of many site-specific factors. The importance of any one factor usually depends on the value of all other factors that influence the environmental characteristics of a site. For sites measured throughout southeast Alaska, 10 to 20 percent of the variation in productivity of understory vegetation was associated with soil type, after the variation associated with canopy cover and stand basal area was accounted for (Alaback 1980, 1982b).

The effect of soil characteristics on vegetation development is most pronounced during the earliest stages of succession, prior to canopy closure. On Prince of Wales Island, clearcuts studied attained only 20 percent of the average understory biomass for their age classes. All of the recent clearcuts with below average productivity were on somewhat poorly drained soils (F1c, F4c soil ecosystems; see footnote 3) which generally give rise to mixed western hemlock-western red cedar forests. Nearby forests on better drained sites (F1n, F1t soil ecosystems) had average to above average understory production for their ages (Alaback 1980).

By contrast, sites located on poorly developed, uplifted beach soils (F1b, F3b) tended to produce above average understory. For uplifted beach sites, tree basal area and sapling density were lower than the average for their age classes. The effect of soils on the understory was more likely an influence on overstory-understory competition than of direct soil interactions with the understory (Alaback 1980).

For older study sites in which tree canopies had closed, the influence of soils on understory productivity was more pronounced on thin, rocky soil types (F2n soil ecosystems; see footnote 3). Most stands on poorly developed soils had understory productivity significantly above average for their age classes. As in the case of poorly developed, uplifted beach soils, the increase in understory productivity on thin, rocky soils was also associated with a less productive and less dense overstory canopy (Alaback 1980).

In evaluating the impact of management on wildlife habitat, the quality of understory vegetation as forage must be considered, along with the amount produced. As the growing season progresses, understory vegetation becomes less nutritious and less palatable to wildlife (Klein 1965). Similarly, as understory vegetation matures following clearcutting, the rate of biomass accumulation decreases (fig. 5). As shrubs mature, annual plant production is higher above the ground and less available to deer and other ground-dwelling wildlife. Such changes must be incorporated into evaluations of the relative benefits of stand-age classes to wildlife; otherwise projections of forage biomass may be overly optimistic. If the longevity of the understory is extended by periodic thinning, for example, older shrubs with a high ratio of woody biomass to annual production could dominate understory production. A kilogram of this type of biomass would be of less value to wildlife than a kilogram of less woody understory vegetation in an old-growth stand.

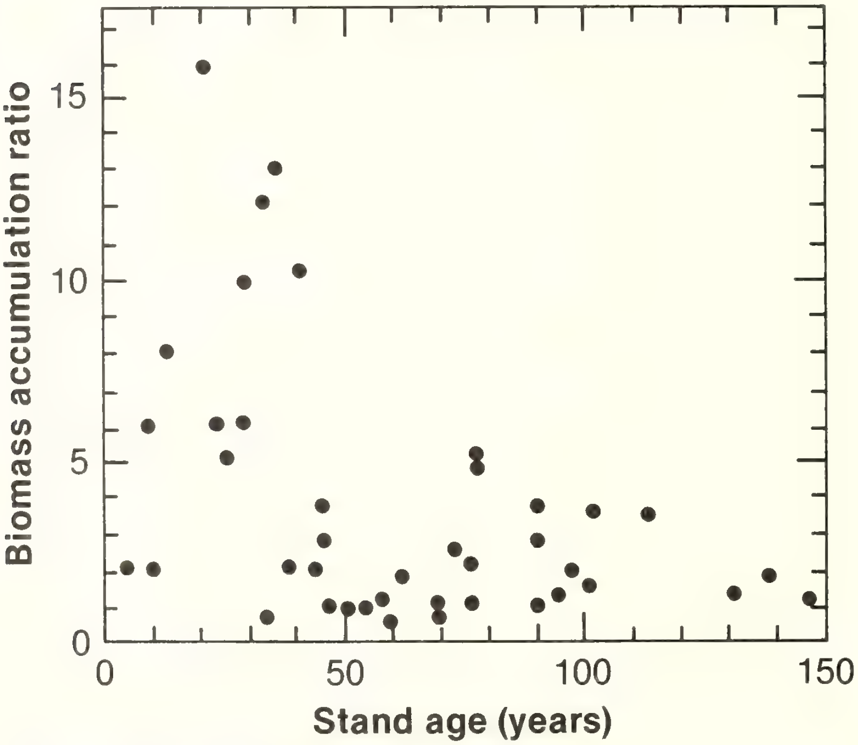

Figure 5.—Changes in understory biomass structure during secondary succession. Biomass accumulation ratio = annual production/total aboveground biomass.

Under ideal conditions (no recent windthrow, homogeneous site conditions, and uniform stocking density), the consequences of forest management on understory vegetation may be predicted on the basis of patterns described for southeast Alaska (Alaback 1982a, 1982b). The consequences of four management strategies are presented in table 7. If the primary objective is to sustain understory structural diversity and herbaceous plant growth, reserving old-growth would be the preferred alternative. Rotations of 300 years would be the next best alternative.

Repeated thinning may also sustain understory productivity, but there are insufficient data to evaluate how well this would meet the habitat requirements of different wildlife species over a forest rotation. The influence of windthrow on thinned stands, and the consequences to wildlife habitat, also are key factors to consider in evaluating this management strategy (Ruth and Harris 1979).

If an important goal is to improve the carrying capacity of second-growth forests for Sitka black-tailed deer and other wildlife that require high levels of winter forage under closed-canopy forests, then the relationship of forest canopy structure to snow interception and evaporation will have to be considered. Snowpack seriously complicates management strategies, because the open canopies that encourage understory growth also tend to have the deepest snow pack, which may minimize the availability of forage for deer in winter (Harestad 1979).

Research Needs

To assess objectively how best to manage southeast Alaska's forests for both timber production and wildlife habitat we must better understand the relationship of forest and environmental characteristics to understory vegetation. More information is needed on mature and old-growth stands so we can characterize in greater detail the relationship between changes in overstory characteristics and understory productivity over a range of soil and site conditions. We need a much clearer understanding of the relationship between stand characteristics and interception of light and snow. Continued research on basic forest structural relationships may make possible a more precise model of forest overstory-understory relationships and provide objective assessments of management strategies.

Research on the short- and long-term effects of precommercial and commercial thinning on understory vegetation should also provide insights on the response of understory plants to changes in microenvironments and make clearer the practical limitations and opportunities for influencing understory composition and productivity by silvicultural thinning. The reproductive strategies and environmental preferences of understory forage species should also be examined. Detailed information on the response of plant species to environmental changes would provide a realistic basis for modeling the effects of management on understory growth and its value as wildlife habitat.

As the Forest Service manages less productive and more diverse sites for both timber and wildlife, it will be necessary to better define the environmental variation on marginal sites and the consequences of management. Departures from patterns of forest development noted on average to highly productive sites should be expected on marginal sites. An examination of stand development and understory productivity on these marginal sites immediately following clearcutting should provide insight into the way site conditions affect the course of plant succession, with resulting consequences for wildlife. Although decades of monitoring permanent plots may be necessary to a complete understanding of how soil and site factors influence forest and wildlife productivity over the course of a timber rotation, studies of early successional development should provide a first approximation of the relationship between site and development of understory.

Management of understory vegetation for wildlife also requires a better understanding of the palatability and nutritional value of common species. Studies of plant nutrition should be related to soil chemistry and ecosystem nutrient cycling, so that the nutritional value of vegetation to wildlife can be related to the response of vegetation to management. Basic information on nutrient storage and cycling in the coastal forests of southeast Alaska is urgently needed. Differences in nutrient cycling in old-growth and second-growth stands should be key topics of future research. Changes in nutrient budgets could have impacts on both forest and wildlife productivity. The climatic and geologic diversity of southeast Alaska make applications of information from fire-dominated, more xeric ecosystems tenuous at best. Questions about the role of understory vegetation in the cycling of nutrients under various soil and site conditions, and management strategies and the consequences of these strategies to wildlife in southeast Alaska, remain unanswered.

Metric Equivalents

1 kilogram/hectare (kg/ha) = 0.8922 pounds/acre
1 kilogram (kg) = 2.2046 pounds
1 hectare (ha) = 2.47 acres
1 square meter (m^2) = 10.764 square feet
1 meter (m) = 39.37 inches
1 m^2/hectare = 4.356 square feet/acre

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Appendix

Common and Scientific Names of Plants[1]

Common name	Scientific name
Alaska blueberry	*Vaccinium alaskaense*
Alaska willow	*Salix alaxensis*
Bearberry	*Arctostaphylos alpinum*
Black cottonwood	*Populus trichocarpa*
Bunchberry	*Cornus canadensis*
Coralroot	*Corallorhiza maculata*
Devils club	*Oplopanax horridum*
Fernleaf goldthread	*Coptis asplenifolia*
Fireweed	*Epilobium angustifolium*
Five-leaf bramble	*Rubus pedatus*
Foamflower	*Tiarella trifoliata*
Horsetail	*Equisetum arvense*
Dryas species	*Dryas*
Ladyfern	*Athyrium filix-femina*
Mountain hemlock	*Tsuga mertensiana*
Oakfern	*Gymnocarpium dryopteris*
Oval-leaf huckleberry	*Vaccinium ovalifolium*
Pacific silver fir	*Abies amabilis*
Red alder	*Alnus rubra*
Red huckleberry	*Vaccinium parvifolium*
Rusty menziesia	*Menziesia ferruginea*
Salmonberry	*Rubus spectabilis*
Single delight	*Moneses uniflora*
Sitka alder	*Alnus sinuata*
Sitka spruce	*Picea sitchensis*
Sitka willow	*Salix sitchensis*
Spreading wood fern	*Dryopteris austriaca*
Subalpine fir	*Abies lasiocarpa*
Trailing black currant	*Ribes laxiflorum*
Western hemlock	*Tsuga heterophylla*
Western red cedar	*Thuja plicata*

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[1] Nomenclature follows Hultén 1968.

Alaback, Paul B. Secondary succession following logging in the Sitka spruce-western hemlock forests of southeast Alaska: Implications for wildlife management. Gen. Tech. Rep. PNW-173. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 26 p.

Preliminary information on general landscape patterns in southeast Alaska suggests that two major, compositionally distinct vegetation zones can be defined for the closed-forest type: western hemlock-Sitka spruce/Alaska huckleberry/ bunchberry on the uplands, and Sitka spruce/devils club-salmonberry on alluvial flats and terraces.

Recent clearcuts (0 to 30 years old) produce the most shrubby vegetation of any age class in the forest succession. Even-aged forests (30 to 150 years old) produce the least understory vegetation. Uneven aged, old-growth forests sustain the most structurally diverse understory vegetation. Forests with open, patchy canopies tend to produce the most understory vegetation. More data is needed before forest management techniques can be successfully used to improve the quality of habitat for wildlife over that presently found in unmanaged old-growth forests.

Keywords: Succession (secondary), biomass, understory layer, logging effects, logging (-wildlife, old-growth stands, wildlife management, Alaska (southeast), western hemlock, Sitka spruce.

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Pacific Northwest
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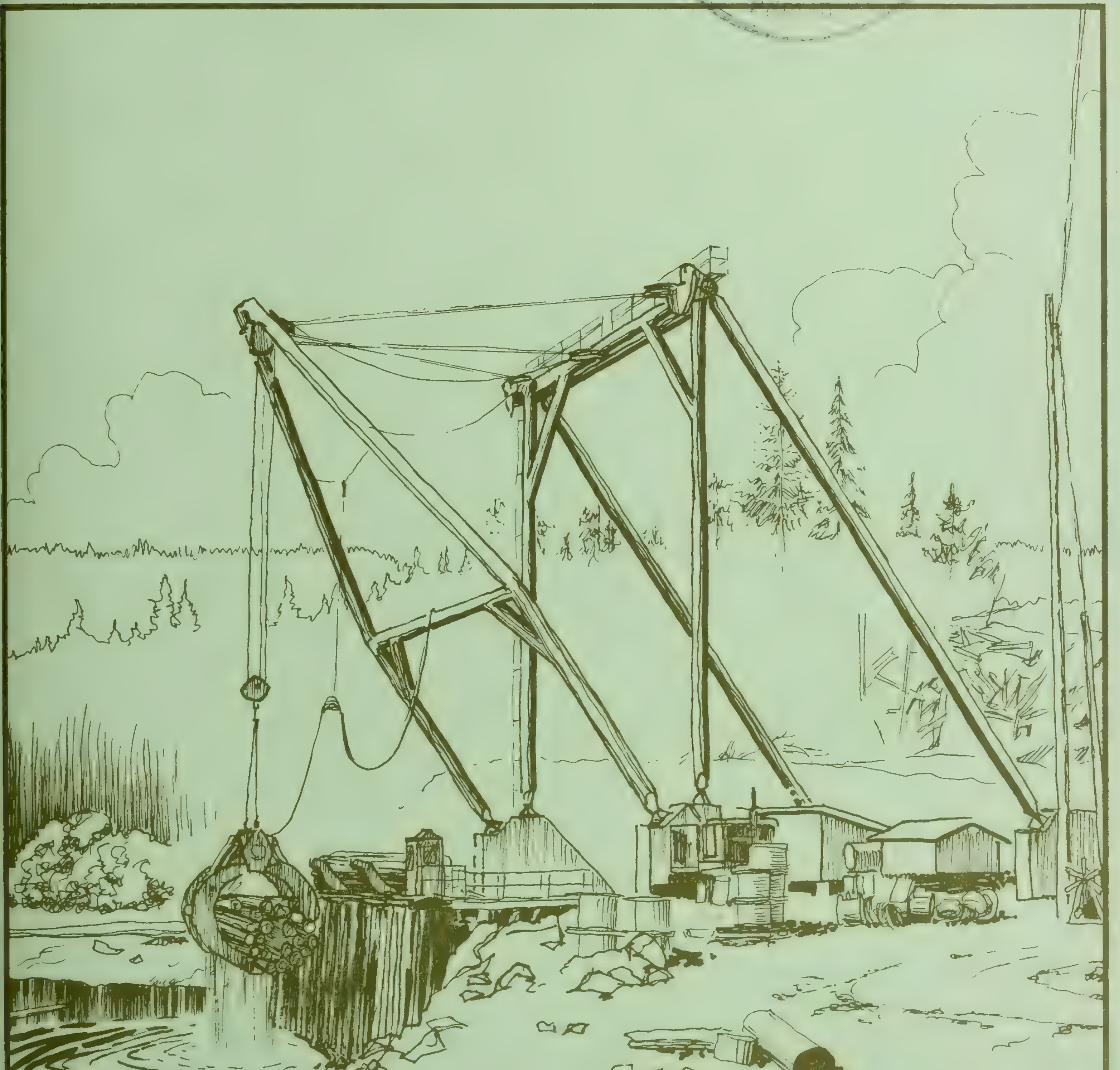
General Technical
Report
PNW-174

April 1985

Log Transfer and Storage Facilities in Southeast Alaska: A Review

Tamra L. Faris and Kenneth D. Vaughan



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Abstract

Faris, Tamra L.; Vaughan, Kenneth D. Log transfer and storage facilities in southeast Alaska: a review. Gen. Tech. Rep. PNW-174. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985.** 24 p., plus map.

The volume of timber harvested in southeast Alaska betweeen 1909 and 1983 was 14,689 million board feet; nearly all was transported on water to various destinations for processing. In 1971 there were 69 active log transfer and storage facilities and 38 raft collecting and storage facilities in southeast Alaska. In 1983 there were 90 log transfer sites, 49 log storage sites, 228 sites proposed for log transfer development, and 12 sites proposed for log storage development. We calculated that there were 176 acres of estuarine habitat covered by bark from 90 log transfer sites in 1982. Additional habitat was covered by bark at log storage sites. In 1981, approximately 1,388 acres would have been covered by log rafts at some time. The statistics for numbers of log transfer and storage sites no longer in use are too incomplete for use in estimating bark coverage.

The options for handling logs at a saltwater facility are land-to-water (rafting), land-to-vessel (barging or shipping), and land-to-water-to-ship (loading barge or ship from water). The A-frame has been the preferred device for log transfer because of operating economy and availability. Other transfer methods include chain conveyors, "beaver slide" ramps, and rockfill ramps.

Keywords: Log transfer, log storage, Alaska (southeast), southeast Alaska.

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Introduction

Timber harvest was begun in the early 1900's in southeast Alaska, but became a major economic influence only in the 1950's (Selkregg 1974). The total volume of timber harvested from the Tongass National Forest between 1909 and 1983 was 14,689 million board feet;[1] nearly all of this timber was transported on water to various destinations for processing. Because fishery resources are related to habitat quality, fish habitat needs to be protected where log transfer and storage sites occur over biologically productive portions of the estuaries.

Log transfer activities and their related effects on the marine environment of southeast Alaska have been of concern since the early 1970's. Several reviews discuss the types of environmental problems encountered with log transfer and storage in estuarine habitat[2] (Hansen and others 1971, Koski and Walter 1978, Sedell and Duval in press, Toews and Brownlee 1981).

Environmental concern centers on five basic types of disturbance caused by log transportation activities:

1. Bark and wood lost into the marine environment with resultant physical, chemical, and biological effects.

2. Compression of substrate, shading of water column, and breakwater effect of rafts.

3. Modifications to the shoreline and intertidal areas to accommodate the facilities and equipment.

4. Presence of log transfer and storage facilities, which create conflicts over access among resource users.

5. Effects of facilities associated with logging and log transfer operations, such as fuel transfer facilities, camps, and docks, that increase the likelihood of other environmental impacts.

Coves and bays are often the most biologically productive portions of an estuarine system. They also provide the best protection from wind and swell and, therefore, are preferred locations for log transfer and storage. The topography of the islands and mainland of southeast Alaska is mountainous with steep cliffs and slopes: a stream at the head of each valley drains into an estuary. "Natural corridors" for roads also terminate near the valley head rather than traverse steep topography to connect with another drainage. Areas with adjacent freshwater inputs are also chosen for log storage because of the assumption that an area with lower salinity has increased protection from marine borers (*Bankia setacea*). Although fresh water does kill marine borers, the effectiveness of freshwater influence has not been documented for intertidal waters in southeast Alaska.

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[1] Reports on file, USDA Forest Service, Alaska Region, Federal Office Building, Box 1628, Juneau, AK 99802.

[2] Unpublished report, 1980, "A Review of the Impacts of Log Handling on Coastal Marine Environments and Resources," by Wayne S. Duval and F. F. Slaney, prepared for the Council of Forest Industries. On file at Environmental Sciences Limited, Vancouver, British Columbia.

Estuaries used for log transfer and storage are affected to varying degrees by the accumulation of bark and woody debris around the entry and storage sites and by physical modifications such as fill, riprap, and piling. Bark sluffed during transfer and storage can accumulate, cover the bottom, and smother existing habitat and sessile organisms. There are indications that water quality around or in bark accumulations is also affected to varying degrees[3] (Pease 1974). The amount of dilution or flushing is the main factor determining effects near the transfer or storage sites.

This paper consolidates information on the numbers of log transfer and storage sites and presents an overview of the design and biological problems that arise from location of these facilities. Included is a summary of the features of transfer facilities and ideas on siting and engineering design. The purpose is to review and quantify, in part, impacts the timber harvest industry has on intertidal and estuarine habitat. Such a review may be useful for planning and evaluation of future tideland uses.

Sources of Records on Log Transfer and Storage Sites

The number of log transfer facilities in southeast Alaska was determined from the records of permitted or leased facilities and public easements. Management of the tidelands used for that purpose was transferred to the State of Alaska in 1959. Log transfer and storage activities that affect navigable waterways are also regulated by other authorities: Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403), Sections 404 and 401 of the Clean Water Act (33 U.S.C. 1344), the Fish and Wildlife Coordination Act (16 U.S.C. 661-663), and Section 307 of the Coastal Zone Management Act (PL 92-583).

The Corps of Engineers issues Department of the Army permits to perform work in or affecting navigable waters pursuant to Section 10 of the Rivers and Harbors Act, or to discharge dredged or fill material into waters pursuant to Section 404 of the Clean Water Act (Kyle 1982, State of Alaska 1981). The Corps of Engineers identifies activities by name of a nearby waterway and a unique number under the heading of that waterway.

The State of Alaska also has a permit and leasing system for activities on State-owned tideland and submerged land. Applications are numbered, filed consecutively and, when approved, plotted on maps. The facility drawings and location references are usually the same as those submitted for the Department of the Army permits.

Since summer 1982, the Alaska Department of Natural Resources (ADNR) has issued easements for access in the Tongass National Forest. Log transfer is usually the initial purpose for the easement, but it is a permanent easement that also can be used for forest management, contract work, recreation, or other commercial access at the site. Mapping the easement and marking it with monuments are stipulated by the State and by the USDA Forest Service.

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[3] Personal communication, Charles O'Clair, National Marine Fisheries Service, Auke Bay Laboratory, Auke Bay, AK 99821.

Spear[4] notes that permit records were not always accurate representations of actual facilities. For instance, a permit may have been granted, but the facility may never have been built. Many facilities do not resemble the plans that were originally submitted. No studies have quantified the divergencies from actual permitted activities. Spear also noted a lack of uniformity in the information from the Corps of Engineers in terms of timeliness of activities and terminology used. The words "destroyed," "removed," and "abandoned" all mean the facility is not presently in use, but its condition is unknown. Unless the information is provided in applications, the Corps of Engineers or ADNR are not usually aware if a facility is closed permanently or just for a few years until timber harvest in that drainage resumes.

Number of Log Transfer and Storage Sites

Summaries of the number of permits are not available from either the Corps of Engineers or the ADNR. Records have not been maintained of active log transfer sites or of the degree of activity. The Alaska Department of Environmental Conservation (ADEC) has two inventories of log transfer and storage sites. The first inventory (Wells 1971) found 69 active log transfer and storage facilities and 38 raft collecting and storage facilities in southeast Alaska. The second inventory (see footnote 4) did not summarize the data, but rather plotted on maps those facilities then in use. This 1976 inventory showed 43 active log transfer and storage sites and 47 raft collecting and storage sites. It is not known which of these sites were established since the 1971 inventory. In addition there is a Directory of Permits (Alaska Department of Environmental Conservation 1978 with 1979 update) that lists all tideland users according to location and a marine facilities coastal inventory which lists permits.[5]

The number of sites used for log transfer at any given time depends on timber market and harvest schedules. Most sites are used intermittently; that is, a site is built for a specific harvest period, then after the harvest in that area is completed, the Department of the Army permit and the State tidelands lease may be kept active for future timber harvests or allowed to terminate. The USDA Forest Service is planning for more frequent use of sites for log transfer due to increased activity with salvage sales and for a USDA Forest Service-Small Business Administration set-aside program to direct preparation of smaller sale volumes. This may increase periodic reuse of facilities over an extended period with associated chronic environmental impacts.

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[4] A preliminary inventory of coastal timber industry facilities and operations, 1976, by Andrew M. Spear, prepared by Water Programs/Environmental Analysis Section, Alaska Department of Environmental Conservation, through a Reimbursable Services Agreement for the Alaska Coastal Management Program, Juneau, AK. 32 pages and a separate 102-page map section.

[5] Unpublished data, 1975, "Marine Facilities Coastal Inventory," by Tryck, Nyman and Hayes, Juneau, AK. 1,197 pages. On file at the State of Alaska, Department of Environmental Conservation library, Juneau, AK 99802.

Table 1—Summary of the number and type of timber transportation facilities as plotted on the map, "Southeast Alaska Tideland Locations for Log Transfer and Storage" (located in cover pocket)

Type of facility	Forest Service administrative areas			
	Chatham 1/	Stikine	Ketchikan	Total
Existing log transfer site	23	24	43	90
Existing log storage site	16	18	15	49
Proposed log transfer site 2/ 3/	103	43	82	228
Alternate proposed log transfer site 2/ 3/	8	18	14	40
Proposed log storage site 3/	1	0	11	12
Log transfer site no longer in use	23	10	25	58
Log storage site no longer in use	8	13	19	40
Major processing center	2	2	6	10

1/ Includes Yakutat and State lands in the Haines area.

2/ Alternate sites were not included in the number of "proposed log transfer sites" because presumably only one will be developed--either the one proposed or its alternate.

3/ The time horizon for construction of proposed sites is 50 years.

The map, "Southeast Alaska Tideland Locations for Log Transfer and Storage" (located in cover pocket), reflects information from many sources but is largely base on the ADNR land status maps. No judgments on the economic or biological value of the sites indicated as "proposed for future development" were made. The source maps were prepared based on information provided by the USDA Forest Service, private landowners, and industry. The compiled information in table 1 reflects the summation from all the sources of information. The forest supervisors of the Tongass National Forest provided much of the initial information to the ADNR and refined the information concerning the National Forest. The map was also condensed (fig. 1) to show frequency and distribution of log transfer and storage activities.

The number of active log transfer sites in southeast Alaska, as shown on the map, appears to be related to the volume of timber harvested (roughly 10 million board feet per site was harvested). The total timber volume cut in the Tongass National Forest peaked in 1973 at 588 million board feet, and the peak reported for southeast Alaska occurred the same year at 599 million board feet (table 2). In 1971, during Wells' inventory, harvest was 528 million board feet from the Tongass National Forest and there were 69 active log transfer and storage facilities. In 1976, harvest was 463 million board feet and there were 43 active log transfer and storage sites (see footnote 4). In 1981, harvest was 386 million board feet and there were 87 log transfer sites under permit, although less than 40 were active. Timber harvest in the Tongass National Forest is now set at 4.5 billion board feet per decade by the Alaska National Interest Lands Conservation Act. The trend toward sales of smaller volume will result in a larger number of permitted sites with each handling a lower volume of timber.

A total of 228 new log transfer sites and 12 new storage sites have been identified for possible development in the next 50 years. Depending on review by State and Federal agencies and the constraints imposed on the developer, alternative sites may be chosen and some may never be developed.

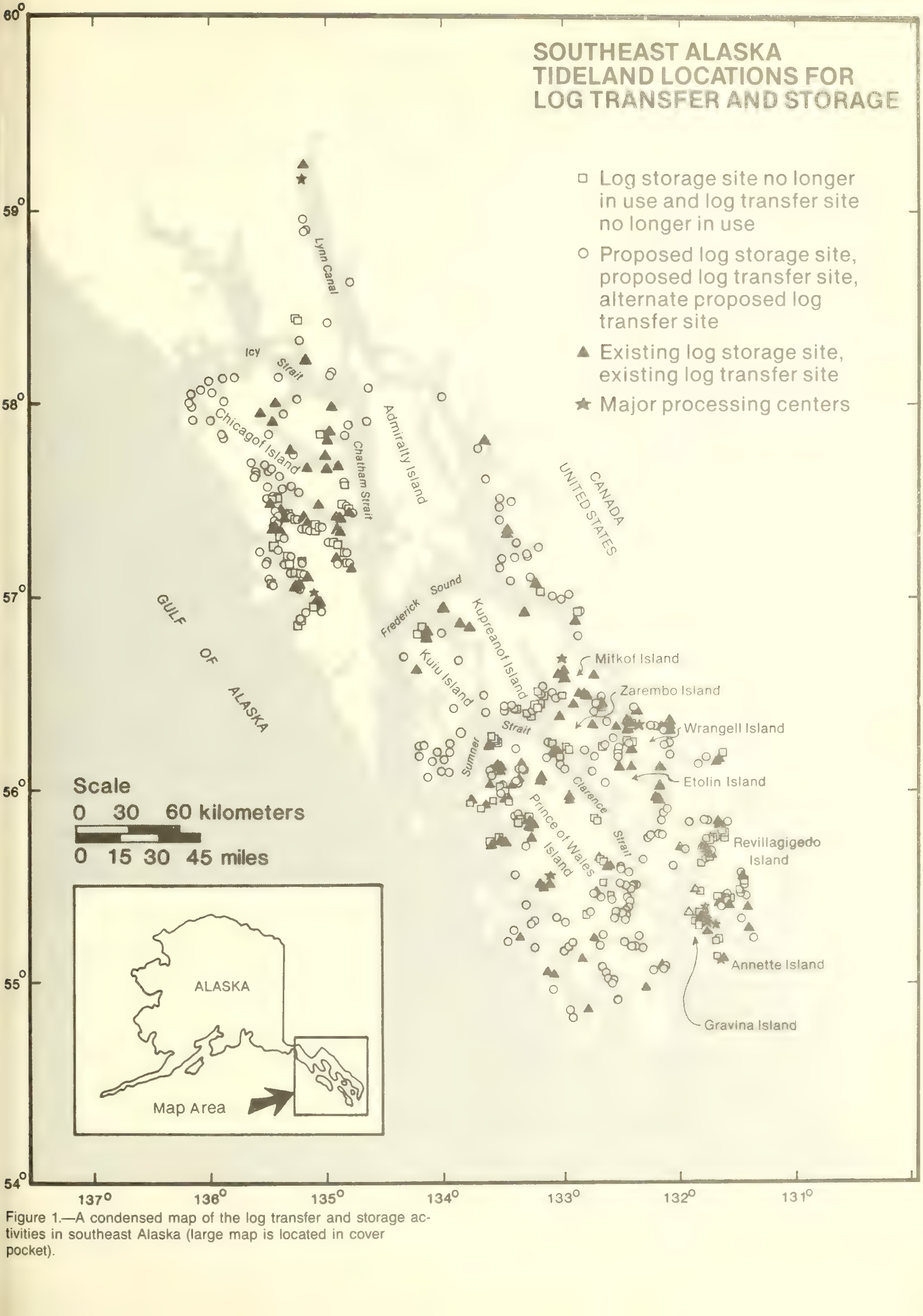

Figure 1.—A condensed map of the log transfer and storage activities in southeast Alaska (large map is located in cover pocket).

Table 2—Timber harvested in southeast Alaska, including the Yakutat area, in thousand board feet

Year	Tongass National Forest 1/	Alaska State lands 2/	Private lands 3/	Total
1909-16	234,488	--	--	234,488
1917	41,002	--	--	41,002
1918	43,114	--	--	43,114
1919	37,374	--	--	37,374
1920	45,609	--	--	45,609
1921	11,651	--	--	11,651
1922	20,623	--	--	20,623
1923	40,463	--	--	40,463
1924	48,646	--	--	48,646
1925	53,723	--	--	53,723
1926	50,992	--	--	50,992
1927	52,000	--	--	52,000
1928	33,766	--	--	33,766
1929	42,015	--	--	42,015
1930	38,517	--	--	38,517
1931	18,234	--	--	18,234
1932	14,699	--	--	14,699
1933	14,664	--	--	14,664
1934	28,151	--	--	28,151
1935	30,454	--	--	30,454
1936	39,964	--	--	39,964
1937	35,316	--	--	35,316
1938	25,585	--	--	25,585
1939	26,492	--	--	26,492
1940	30,861	--	--	30,861
1941	35,787	--	--	35,787
1942	38,535	--	--	38,535
1943	73,590	--	--	73,590
1944	86,840	--	--	86,840
1945	58,268	--	--	58,268
1946	48,952	--	--	48,952
1947	83,385	--	--	83,385
1948	81,010	--	--	81,010
1949	49,220	--	--	49,220
1950	54,435	--	--	54,435
1951	52,894	--	--	52,894
1952	63,357	--	--	63,357
1953	59,196	--	--	59,196
1954	109,237	--	--	109,237
1955	213,785	--	--	213,785
1956	230,198	--	--	230,198
1957	226,383	--	--	226,383
1958	167,520	--	--	167,520
1959	266,591	--	--	266,591

Table 2—Timber harvested in southeast Alaska, including the Yakutat area, in thousand board feet (continued)

Year	Tongass National Forest 1/	Alaska State lands 2/	Private lands 3/	Total
1960	347,496	210	--	347,706
1961	338,207	4/ 1,967	--	340,174
1962	366,276	4/ 6,872	--	373,148
1963	395,143	4/ 10,633	--	405,776
1964	443,736	4/ 18,144	--	461,880
1965	397,610	4/ 24,161	--	421,771
1966	474,277	20,594	--	494,871
1967	474,337	45,701	--	520,038
1968	529,496	41,411	--	570,907
1969	519,343	33,506	--	552,849
1970	560,081	35,876	--	595,957
1971	527,737	26,737	--	554,474
1972	547,500	24,920	--	572,420
1973	588,491	10,419	--	598,910
1974	544,025	6,806	--	550,831
1975	408,371	3,289	--	411,660
1976	462,776	350	--	463,126
1977	447,332	4,636	--	451,968
1978	398,700	3,453	--	402,153
1979	453,194	729	--	453,923
1980	452,122	5,111	70,300	527,533
1981	385,685	6,786	5/ 122,000	514,471
1982	344,857	5/ 5,400	5/ 209,200	559,457
1983	251,177	5/ 2,500	5/ 232,000	485,677
Total	13,715,555	340,211	633,500	14,689,266

1/ "USDA Forest Service Cut & Sold Report," and other reports, assembled by Dan MacPherson, U.S. Department of Agriculture, Forest Service, Alaska Region, Juneau, AK 99802. Figures include utility grade logs.

2/ Personal communication, Craig Olson, Alaska Department of Natural Resources, Pouch 7-005, Anchorage, AK 99510. Almost all the cut was from the Haines area and was milled at the Schnabel Lumber Co. mill and did not go into the water for transport.

3/ Saddler 1982.

4/ Figures for these years include northern Alaska harvest which was a small amount compared to southeast Alaska harvest.

5/ Values taken from the draft report, "Timber Supply Demand Report, 1983," U.S. Department of Agriculture, Forest Service, Alaska Region, Juneau, AK 99802.

The number of long-term raft storage sites has remained fairly constant over the past 20 years. Forty-nine log storage sites are now permitted; 40 storage sites have been abandoned; 12 storage sites are proposed. This ratio is as expected since the sites are located in protected areas along established raft-towing routes; therefore, the best sites have already been developed and remain in use. This could change following a change in location of harvest areas or raft-towing routes. The intensity with which a storage site is used depends on the weather and timber market in the short term and trends in transportation in the long term.

Effects of Primary Manufacture Requirements

Timber harvested from National Forest and State lands must, by law, undergo primary processing in Alaska. Primary manufacture usually consists of cutting suitable saw logs into waneys and cants or of chipping the logs for pulp usage. Distance from harvest location to the mill ranges from 5 to 280 miles (Sedlac 1982). Timber harvest on State-owned or privately owned land has been very small in the past (table 2). The only significant sales from State-owned land in southeast Alaska were near Haines where the timber was trucked directly to the mill. This has changed since the Statehood and Alaska Native Claims Settlement Acts transferred extensive areas of forested land in southeast Alaska to private ownership.

It is more financially rewarding to export round rather than processed logs[6] and private landowners have taken advantage of this. As mentioned, timber from National Forest and State lands must undergo primary manufacture within the State prior to export or interstate shipment. Transportation from the harvest site to a milling location is necessary prior to shipping to a market. For round-log export, loading points from land to water to ship, or from land to ship, are needed reasonably near the harvest site. If land-to-ship loading facilities are constructed, the potential environmental impacts change from debris accumulation in the water to quantity of habitat used to construct the facility and to facility-related pollutants.

Estuarine Area Affected by Bark and Debris Accumulations

The percentage of estuarine or cove and bay areas currently covered by bark deposits from log transfer activities is based on an estimate of the total area of estuary in southeast Alaska. This is complicated because southeast Alaska consists of many islands and large fiords; thousands of streams and rivers are associated with these features. Depending on the definition of an estuary, the entire Inland Passage of southeast Alaska can be called an estuary, or it can be divided into hundreds of smaller estuaries.

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[6] Unpublished administrative report, 1984, "Timber Supply and Demand, 1983," by Joseph R. Mehrkens, U.S. Department of Agriculture, Forest Service, Alaska Region, Federal Office Building, Box 1628, Juneau, AK 99802.

Table 3—Estuarine area for Tongass National Forest, southeast Alaska

Management area	Major drainages with estaurine area	Total estuarine area	Estuarine area less than 60 ft. deep	Area less than 60 ft. deep
	Number 1/	- - - - - - Acres	- - - - -	Percent
Chatham	242	807,047	312,058	39
Stikine	87	339,360	225,080	66
Ketchikan	214	425,831	192,364	45
Total	543	1,572,238	729,502	46

1/ These numbers are not intended to represent the number of estuaries, but rather, drainages that terminate in estuaries.

In 1976, the area of all protected bays and estuaries 100 acres or more in size and adjacent to the Tongass National Forest was determined.[7] The areas were calculated by use of a planimeter on maps scaled at 1 inch to the mile. Total estuarine area and the area within each estuary with a depth of 60 feet or less were calculated (table 3). The 60-foot-depth distinction was selected as a result of observations by various resource agency diver-biologists. They observed that the abundance of large macrophytic algal vegetation occurring in the subtidal zone was limited mostly to water depths shoreward of 60 feet.[8] Glacier Bay, upper Lynn Canal, and Annette Island were not included in the original data. Data were recorded for 543 individual areas, which in total do not equal the entire southeast Alaska waterway. Deep, open waterways between islands, such as parts of Chatham, Icy, Sumner, and Clarence Straits and Frederick Sound, were not considered estuaries, although they are definitely influenced by fresh water. This is appropriate for our use because these waterways are not protected areas desirable for log transfer or storage. The estuaries were often divided for the convenience of associating specific areas with major streams, so it was not reasonable to sum the area counts or to conclude that there are 543 estuaries. We therefore summed from data in Blankenship's report (see footnote 7) and found that there are approximately 1,572,238 acres of protected estuarine waters in southeast Alaska.

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[7] Unpublished report, 1976, "Estuary Rating Forms for Tongass Land Management Plan," by John Blankenship, U.S. Fish and Wildlife Service, Box 1287, Juneau, AK 99802.

[8] Personal communication, Ron Berg, U.S. Department of Commerce, National Marine Fisheries Service, Alaska Region, Box 1668, Juneau, Alaska 99802.

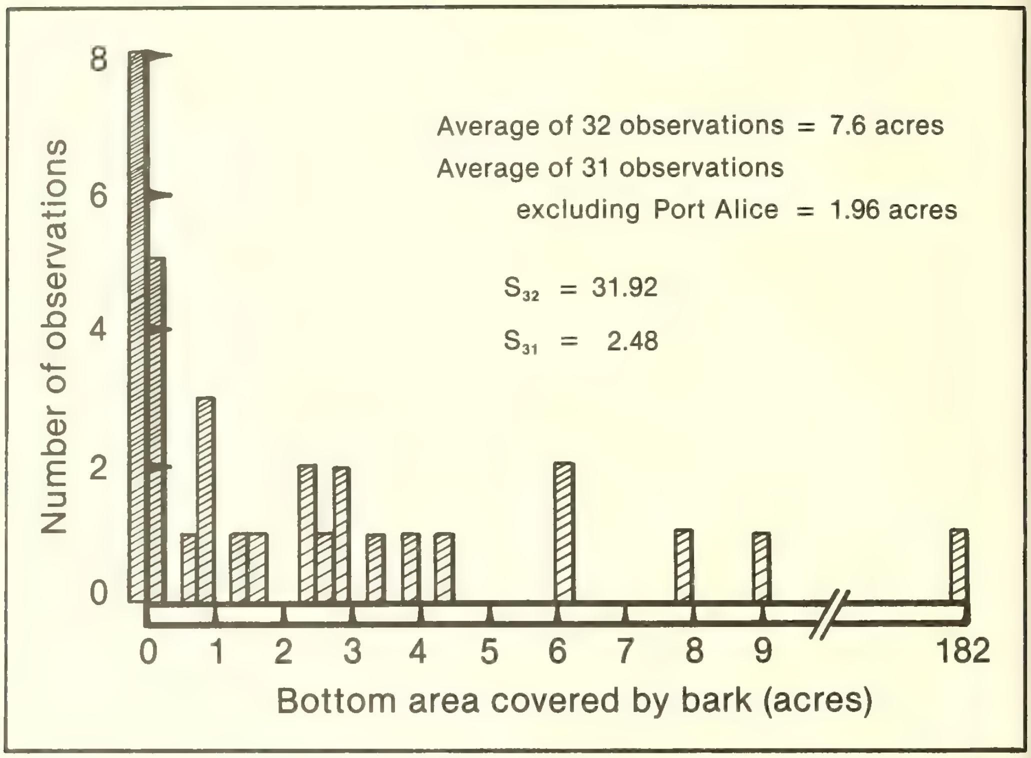

Figure 2.—Occurrences of observations of specific acreages of bark coverage (data from Schultz and Berg 1976). S_{32} is the standard deviation of 32 observations; S_{31} is the standard deviation of 31 observations.

A study of 32 inactive log transfer facilities was conducted in southeast Alaska to measure the area of bark coverage to the 60-foot depth near each transfer facility (Schultz and Berg 1976). For 3l of the sites, the areas covered by bark ranged from 0 to 9.0 acres. The 32d site (Port Alice) had 182.0 acres of bark coverage. Port Alice was not included in calculations in Schultz and Berg (1976) because the location of the site was thought to correspond with an extensive rafting area, and natural accumulation of debris was such that it was not possible to distinguish bark accumulation caused by the transfer facility. Where bark accumulations were too small to measure, or spotty over the area, Schultz and Berg (1976) recorded the area affected as having a "trace." In this report, a "trace" has been approximated at 0.1 acres. The mean bark coverage for the 31 observations was 1.96 acres with a mode of 1.0 acre (fig. 2). This 1.96-acre value represents a weighted average of conditions at only one point in time.

The sites examined ranged from those having recent usage to those not actively used for many years. The amount and location of bottom that is covered by bark may be affected by currents, deposits of silt, and changes in the log transfer operation. Recolonization rates are not known, and it is also uncertain whether or not the habitat is recolonized by the original species present before bark deposition occurred.

A histogram (fig. 2) was developed using data presented by Schultz and Berg (1976), and an empirical probability curve (fig. 3) was generated. The function appearing in figure 3 shows a strong negative exponential fit to the data.

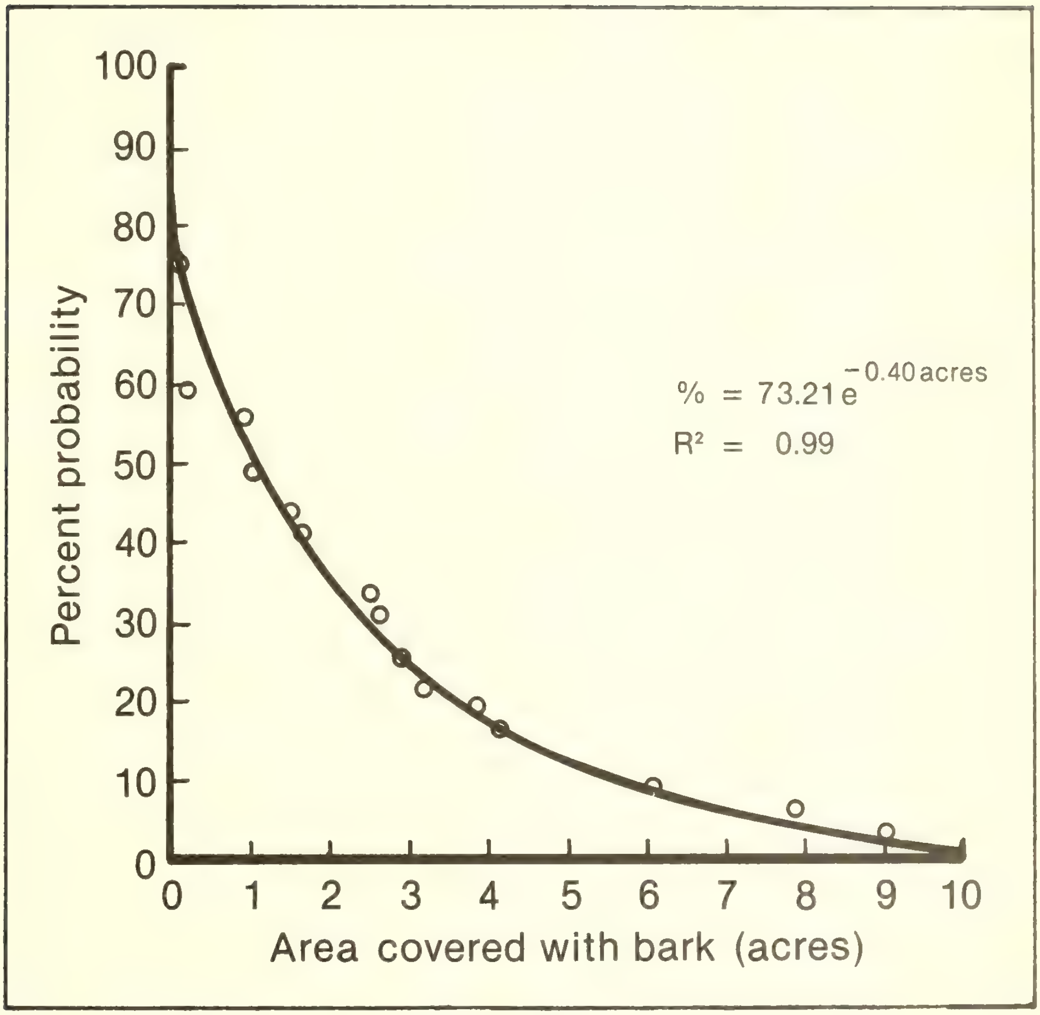

Figure 3.—A predictive model of the probability of exceeding a given acreage of bark covering the estuarine bottom. The curve is a plot of the 31 points of data (excluding Port Alice) in Schultz and Berg (1976).

The length of time debris remains in place after a site becomes inactive is not known and is likely to be highly variable. Bark and debris decay slowly and can remain for many years because of the cold water in the area (Ellis 1970). Fifteen of the sites studied by Schultz and Berg (1976) had been active within the previous 1 to 10 years. The average bark accumulation of these sites was 2.8 acres. Sixteen of the sites had been inactive for periods of 10 to 16 years and had retained an average accumulation of 1.2 acres. This difference suggests the bark and debris accumulation had decreased over time. There have also been changes in sale routine, transfer methods, and size of logs harvested. This may account for differences in area of debris accumulation.

Although 13 of the sites in Schultz and Berg's (1976) study had no accumulation or just a trace of bark or debris directly around the site, the transfer process presumably generated debris that was (1) transported by gradient, currents, or tide to deeper water, (2) covered with sediment, or (3) decayed. Regardless of the dispersal process, accumulations of bark were not measurable at these sites.

Using the 729,502 acres of estuarine area that was less than 60 feet deep (table 3) and the total number of transfer sites shown in inventories, it was possible to estimate the percentage of estuarine area covered by bark accumulations as a result of land-to-water log transfer facilities. This usage was based on the assumption that measurements obtained by divers using scuba gear would not extend to depths much greater than 60 feet. In 1982, there were 90 permitted transfer sites; assuming that an average of 1.96 acres of estuarine bottom at each site was covered with bark and debris, then the total area covered was 176 acres, or 0.02 percent of the total estuarine area that is less than 60 feet deep.

This estimate applies only to log transfer facilities now in use. Additional estuarine habitat is covered by bark and debris from related uses such as (1) log transfer sites no longer in use, (2) log storage sites no longer in use, (3) log storage sites presently in use, and (4) accumulations at depths greater than 60 feet. No data are available for estimating coverage caused by these sources.

Depending on the geophysical aspects of the site, a debris accumulation can decrease by (1) dispersal to deeper water by tidal currents (perhaps accelerated by storms), (2) burial by sedimentation, or (3) decomposition in place. In most cases, a combination of these actions probably occurs. A fourth method of decreasing debris accumulation is mechanical removal by suction dredge, clamshell, or similar equipment. No mechanical removal has yet occurred in southeast Alaska, although it has been stipulated in some Department of the Army permits.

Potential area of coverage by bark and debris can be predicted. The total potential number of log transfer sites (currently permitted plus prosposed) is 317, and the average area of expected bark coverage is 1.96 acres per site. The expected area of accumulation is 621 acres, or 0.09 percent of the available estuarine area that is less than 60 feet deep.

Log storage sites are additional contributors of bark and debris. Beil[9] assumed that the average log raft is approximately 70 feet by 550 feet, or 0.88 acres, and contains 400,000 board feet (2.2 acres per million board feet). Current estimates are shown in table 4. In 1981, timber harvested from the Tongass National Forest totaled 386 million board feet; nearly 100 percent of this timber was bundled into rafts. Approximately 964 rafts were assembled, which in total would have covered 1,388 acres if all rafts had been in the water at the same time. Actual acres occupied at any one time for raft storage were probably much less as the logs were fed continuously through the various mills, but debris could be deposited over an area of approximately equal size. The debris from the rafts will probably accumulate in pockets beneath the most intensively used areas where currents are weakest.

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[9] Unpublished report, 1974, "The Economics of Rafting vs. Barging as a Means of Transporting Logs in Southeast Alaska Waters," by Kenneth E. Beil, International Forestry Consultants, Inc. Report prepared for contract no. 19-200 and is on file at U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3890, Portland, OR 97208.

Table 4—Average log storage area required for various purposes

(In acres)

Use or purpose	Land area	Rafting water area
Unloading of trucks	0.9	0.4
Log bundle storage, log space only	1.0 per million board feet	1.8 per million board feet
Log bundle storage including needed maneuvering space	1.6 per million board feet	3.6 per million board feet

Although the worst case scenario indicates that only a fraction of the estuarine area would be covered by bark, a strong rationale remains to locate that fraction on the least biologically productive portion of the estuary and in places that minimize interference with fishery resources. Changes in water quality that result from bark deposits may affect the entire estuary even though only a small area may be physically impacted.

Design Comparisons for Loading From Land to Water and From Land to Ship or Barge

The methods of putting logs into salt water for transportation to mills have evolved over several decades. In the early years of timber harvest in southeast Alaska (1909 to the 1930's), trees were selected and cut so that they would fall or slide directly into the water (Jackson and Dassow 1974, Rakestraw 1981). As mechanization increased (1940 to 1960), more remote logs were harvested and put into the water with floating A-frame yarders and transfer devices anchored offshore.

The impact on tideland areas from floating A-frame transfer equipment was considered greater than the impact by the more permanent centralized log transfer facilities that came into use in the 1970's. This was because the A-frame breakout points were much more numerous and affected larger areas of habitat. Instead of one large accumulation of debris in the water, the A-frames resulted in continuous deposition of debris and disruption of vegetation along the shoreline. It is not known whether environmental impacts from bark deposits are greater if the bark is spread thinly over a larger area or accumulated more deeply over a small area.

Bark is introduced into estuarine waters at the point of log entry and while the log is handled in the water. Little information is available concerning the differences in amount of debris generated by various methods of transfer into water. The selection of particular processes and equipment is complex.

The two common options for handling logs at a saltwater facility are land-to-water (rafting) and land-to-vessel (barging or shipping). A third option is placing the logs in saltwater and then loading from the water onto barges or ships (land-to-water-to-ship). The types and ranges of impacts are different with each of these methods. Impacts to upland and marine habitats should be evaluated together to determine the best method.

Operating Criteria

The way logs are handled on land affects the range of opportunities for marine handling. The processes used in southeast Alaska are based on the use of log bundles. Logs are sorted on land by species, grade, or intended process. Individual truckloads are normally bundled together using either flat steel bands or, more recently, wire rope. Bundling makes handling easier and significantly reduces the loss of individual logs into the marine environment. Except at mills, sorting of loose logs in the water has been rare for a number of years.

For water storage of logs, the bundles are unloaded and placed in the water in one of several ways. Bundles are moved by boom boats into groups of common species and grades until rafts of approximately 500,000 board feet have been built.

Method of log entry has been the source of much discussion in recent years. The issue of the violence of log entry into the water developed because of the assumption that log entry methods differ in force generated. Greater force may result in greater bark and debris loss. There are no definitive standards for which methods constitute violent or nonviolent entry. The parbuckle system has been examined and found to involve considerable force that dislodges bark (Sedlac 1982). This system involves pulling log bundles off a truck, over a brow log, and skidding them down a set of log skids at about a 40-degree incline. The resulting disturbance, bark loss, and log breakage as the bundles enter the water set an upper limit in our minds for violent entry.

Many of the resource agencies reviewing the permit process say that nonviolent entry is achieved by use of an "easy letdown device," such as a conventional A-frame. The A-frame has been the preferred device for log transfer because of operating economy and availability. An A-frame is either land based and capable of handling log bundles or is mounted to a barge to use for raising and lowering individual logs. The frame is formed by two spars anchored at the base and bound together at the top. A winch system is mounted behind the frame and the lifting cable is passed through a pulley at the top of the frame.

There are two operating versions of the A-frame in use:

1. The fixed-base or single A-frame has the top of the frame guyed into a fixed position. The frame top is located beyond the edge of the loading face. As each bundle is lifted off a truck, it is swung over the water. If the operator does not release the bundle into the water, it will swing back into the equipment. A single drum winch is used to raise and lower the log bundle. The operator thus has little control of the log bundle once it is lifted off the truck, except to release it into the water.

2. The rotating or double A-frame has spars mounted on pivots so that the top of the frame can be rotated from a point over the truck to an entry point over the water. A double-drum winch system is required. One drum moves the top of the frame and the second drum raises and lowers the log bundle. A second A-frame or a spar is mounted between the winch and the rotating A-frame to provide mechanical advantage. The velocity of the log bundle at the point of entry into the water is dependent on operator control, braking equipment, and care exercised in braking the load. This form of A-frame is the most common and is accepted by both the logging industry and regulatory agencies as appropriate for achieving nonviolent log entry. The key feature in the rotating A-frame is that the operator can exercise more control over a log bundle until the attachment arrangement releases in the water. The limiting element on most movable A-frames is the braking capability of the winching systems that lower loads. Almost all existing equipment lacks the capability to brake the loads once they are released without burning out brakes or drums.

Alternative methods to the A-frame include chain conveyors, "beaver slide" ramps, and rockfill ramps. The chain-conveyor systems have been used at a few large installations with high timber volumes. They are relatively more expensive to construct than the A-frames and require the use of a log stacker to unload and handle log bundles. Operational history indicates that breakdowns are frequent and a diver is often required to make repairs. The chain-conveyor systems maximally limit the force applied on entry of bundles into the water.

The beaver slide consists of two to four parallel logs or steel runners set at a 20 to 45 percent angle (11 to 24 degrees). Logs are placed on the runners by a log stacker or end loader and gravity causes them to slide into the water. The initial cost of a slide is lower than the cost of a basic A-frame at a site suitable for either system. The construction cost difference is related to the additional fill near the estuary for the working face and to anchoring an A-frame and winch. The operating costs for the beaver slide devices are expected to be higher, primarily because a log stacker or end loader is needed to handle logs and place them on the runners. A constraint for locating the beaver slide devices is the slope at the site. The runners cannot easily be placed on a slope having less angle than the shore without extensive dredging. The slide is considered a violent entry method by most reviewing agencies because a lot of bark may be dislodged when logs slide down the runners.

The simplest of all log entry systems is a rockfill road that extends to the low tide line. A log stacker moves bundles from the truck to the end of the fill, and the incoming tide floats the bundles off. This method subjects the logs to the least amount of force if logs are unloaded from the trucks carefully and may be the least violent in terms of entry into the water. It is suitable, however, for transferring only the smallest volumes of timber because space on the tideland road for stacking bundles is limited. The tides cycle twice each day and effective use of the available road is possible only on the low and rising tide. The upper portions of the road are not usable because the tide must float the bundle free of the road to avoid blocking the next cycle. The logistics of handling large timber volumes require numerous unloading roads, which would increase impacts to the tidelands.

Land storage of bundles requires clearing of land and construction of operating pads of shot rock. A log stacker or similar equipment capable of handling bundles is required to unload the trucks, lift the bundles back onto trucks, and transport them to the loading face. Land storage is generally required at sites where land-to-barge loading or onsite processing is used. In other circumstances, land storage and sorting is normally at the operator's choice and expense. Table 4 shows the space required for different land and water uses. The space for unloading trucks includes not just unloading space, but turnaround and equipment space. The minimum water area required for moving the log bundles into the water and handling bundles is in addition to this value. Maneuvering area and space between the unloading face and the water storage location are not included. Additional service facilities such as boat docks and unloading ramps are also not included.

Design Guidelines

Log entry facilities are designed to meet a functional purpose at a reasonable cost and reasonable risk of failure. Table 5 contains a summary of physical requirements that must be met to accommodate the various types of log entry systems. These may be considered as guidelines for (1) the operating systems available, (2) the acceptable risks of damage to the facility and operating equipment, (3) safety to the operators, and (4) environmental considerations.

Comparison of Facility Designs

Four designs for marine facilities used for log transfer are compared here to illustrate the range of environmental and logistical constraints. Two of the designs are for land-to-water (rafting) operations at Deep Bay and Little Hamilton Bay. The third and fourth are possible designs for land-to-barge and land-to-water facilities developed for Whitestone Harbor. The projects represent state-of-the-art log transfer facility design practices.

The primary differences among the three sites are the slope of the intertidal and subtidal bottoms, and the upland topography. The area of construction activity on land and in the estuarine zone is much larger for the land-to-barge facility than for the land-to-water facilities. The impact on the marine environment from water storage of logs is larger if rafting is used. Eight rafts of 500,000 board feet each will temporarily occupy 7.2 acres. The respective land and water areas involved for the different designs are compared in table 6.

Differences in design are apparent between Deep Bay and Whitestone Harbor; the former is a pile-supported structure at the working face, and the latter is a cellular structure of sheet piling. There is also a difference in working depth and in the length and area at the face. Figures 4 and 5 are plan views of the Whitestone Harbor and Little Hamilton Bay sites, respectively. Figure 6 shows the cross section typical of the facilities at the two land-to-water sites.

(Text continues on page 22.)

Table 5—Physical requirements, in feet, for log transfer facilities

Design element	Land-to-water transfer	Land-to-barge transfer
Height above mean low tide 1/	+24	+24
Depth at face below mean low tide 2/	3/ -5	4/ -25
Minimum face length: 5/		
Single bundle	60	60
Double bundle	not used	120
Access width: 6/		
Minimum clearing width	7/ 40	6/ 80
Surface width	16	24
Road grade to operating zone/face: 8/		
Maximum road grade (favorable)	9/ 10	10/ 6
Desirable limits	± 4	± 2

1/ The height above mean low tide to the operating surface provides clearance above average high tides. It is accepted that overtopping by waves or storm surges at maximum tidal conditions will occasionally occur.

2/ The working faces of the structures need to be located with a depth and freeboard for the intended water transportation method. The depth at the face below mean low tide is based on acceptance of occasional operational delays when minus tides occur. The effects of the delays are considered minimal when compared to the cost and impacts of construction in deeper water.

3/ The land-to-water loading methods are designed to place log bundles into the water without hitting the bottom substrate (grounding). By limiting operation to plus tides, the fill into the estuarine area can be limited to the area above minus 5-foot levels. The operating limitations are not unnecessarily severe, as the minus tides tend to occur in the spring and in the very early mornings. Trucks loaded with logs would not normally arrive from landings until after the tide had returned to mean low levels.

4/ The depth at the face for land-to-barge loading was selected on the basis of current and anticipated future drafts of barging vessels. Although the draft for small, flat-bottomed barges is as little as 8 feet, these vessels can carry only about 100,000 board feet of timber. The only dedicated log-carrying barge in use in southeast Alaska in 1983 (the Silver Bay) required a minimum loaded draft of 14 feet. Log transportation vessels currently in use in British Columbia have loaded drafts approaching and, in some cases, exceeding 20 feet. With replacement costs of log transport vessels ranging up to $24 million, and the possibility of hemlock butts sinking, vessel safety requires that a depth of ±24 feet below mean low tide be used as the shallowest depth that vessel owners (and insurers) will reasonably risk.

(Footnotes continue on next page.)

Table 5—Physical requirements, in feet, for log transfer facilities (continued)

5/ The face length must be adequate for the log bundles expected at the site. Off-highway loads used on forest development roads do not normally have maximum load length restrictions. The maximum truck load weight of 102.5 tons gross vehicle weight limits the weight of the log bundle to approximately 80 tons. Bundles up to 50 feet in length are not uncommon. With an additional 10 feet needed for equipment operation, the minimum design guideline is approximately 60 feet. The future use of barging will depend on cost and loading efficiency. The most efficient and cost effective vessels are large and fast loading. These vessels use two cranes to move volumes of up to 3 million board feet at a time. Costs associated with delays will create pressure that favors speedier loading. Faces wide enough to allow two cranes to operate simultaneously will be needed to meet the necessary operating efficiency. A tradeoff to be evaluated is the greater quantity of fill placed on the tidelands to create the double width operational advantage for more efficient barge loading.

6/ The handling equipment at land-to-barge facilities is usually a log stacker. This is a massive piece of equipment designed to move 40- to 80-ton bundles of logs. The logs are carried in jaws at the front of the machine. The operator cannot always pick up bundles at the center of the logs; therefore, width of passage must be sufficient to allow the full length of the bundle to pass with a safety allowance on both ends (minimum 80 feet). The width of the stacker and limits on maneuverability require a 24-foot minimum road surface width. Road widths to 30 feet are not unreasonable, particularly where soft shoulders present a risk of overturning.

7/ The equipment used for road construction will usually require a clearing 40 feet wide to provide clearance for the swing of the backhoe.

8/ Access grades are limited by the vehicles using the travelway. Loaded vehicles approach the tidelands on a down grade. A factor limiting design is the operational consideration of braking and stopping as the vehicle nears the face of the water access point. The stacker cannot operate on steep grades--even on grades that a truck could traverse easily. Braking ability and probability of serious equipment damage limit the maximum desirable grade for a log stacker to ±2 percent. With additional braking kits, disc brakes, and careful operation, grades up to an absolute maximum of 6 percent (downhill) can be safely negotiated by log stackers.

9/ Based on controlling and stopping a U-102 (102.5-ton gross vehicle weight) truck on a grade.

10/ Maximum recommended, sustained, favorable grade for log stackers. Equipment may exceed this grade only at higher risk. Maximum grade is based on disc brakes and installation of additional braking kits. Vehicles when loaded are capable of maximum adverse grade of 15 percent.

Table 6—Land and estuarine areas involved in construction of log transfer facilities at three sites in southeast Alaska

Site	Land area	Estuarine area	Slope of bottom at the face
	- - - - Acres	- - - -	Percent
Deep Bay	[1] 0.80	0.44	24
Little Hamilton Bay	[1] 1.11	.31	27
Whitestone Harbor:			
Land-to-water	[2] 0	.83	14
Land-to-barge	[3] 17.7	1.71	11

[1] Land area from site access road to mean high tide.

[2] All construction is beyond mean high tide except access road.

[3] Land area for log storage and access; only width in excess of access road included.

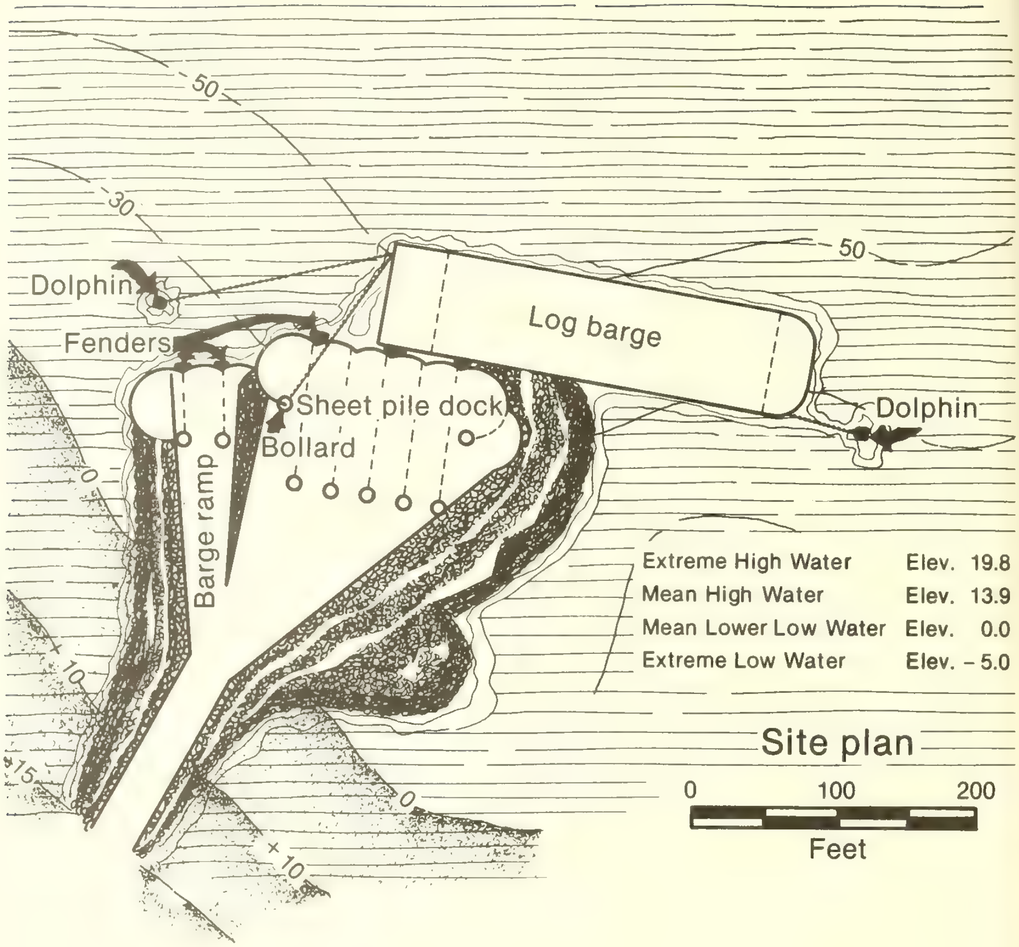
50
30
Dolphin
Fenders
Log barge
50
Sheet pile dock
Bollard
Dolphin
Barge ramp
0
10
15
0
10
Extreme High Water Elev. 19.8
Mean High Water Elev. 13.9
Mean Lower Low Water Elev. 0.0
Extreme Low Water Elev. - 5.0
Site plan
0
100
200
Feet

Figure 4.—Plan of a proposed land-to-barge transfer facility at Whitestone Harbor, Chichagof Island.

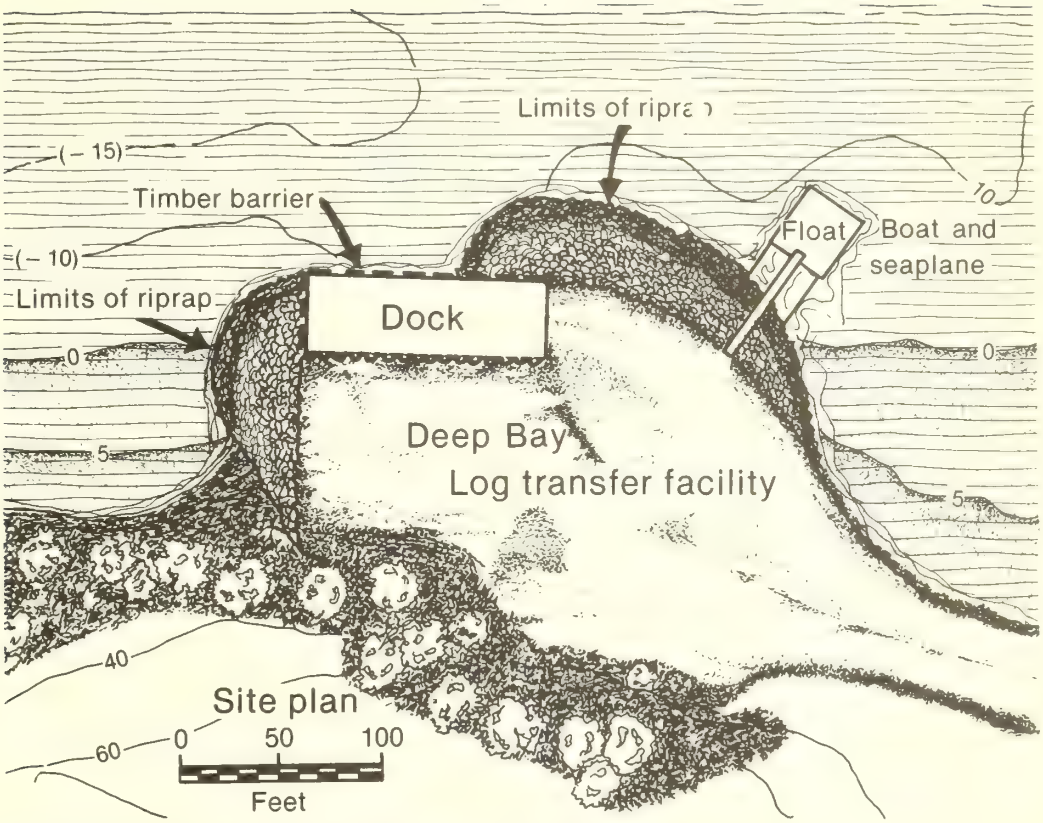

Figure 5.—Plan of a land-to-water log transfer facility at Deep Bay.

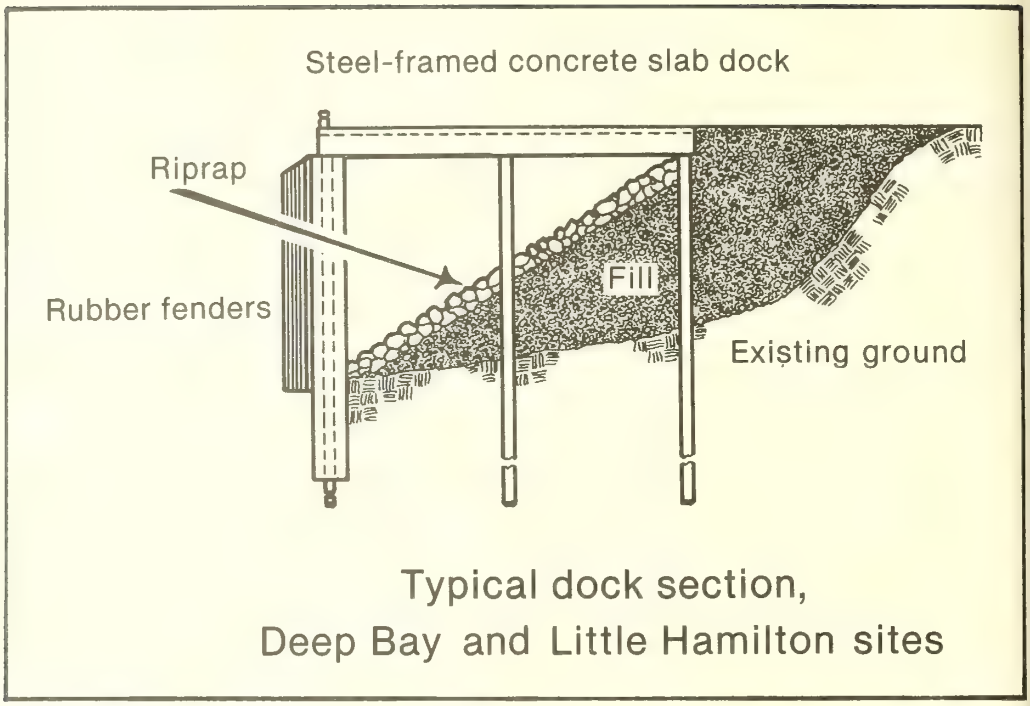
Steel-framed concrete slab dock
Riprap
Rubber fenders
Fill
Existing ground
Typical dock section,
Deep Bay and Little Hamilton sites

Figure 6.—Cross sectional view of a land-to-water log transfer facility in use at both Little Hamilton Bay and Deep Bay.

The view of the Little Hamilton Bay site (fig. 6) shows the recommended 1-percent slope from working face to the shore. This directs surface drainage away from the face of the fill and into filter strips prior to discharge. The result is less suspended solids in the runoff into the estaurine area. The slope also provides a safety measure for vehicles: vehicles will not tend to roll to or over the edge of the face. The Whitestone Harbor land-to-barge configuration precludes use of this design. The bridge designed to broach the intertidal area creates, in effect, an island with limited options for management of surface runoff. The only moderately practical alternative to overland discharge of runoff at the island is the collection of drainage into a catch basin and subsequent percolation into the rock fill. These installations have short useful lives because the suspended solids rapidly plug the drainage through the fill. Construction of a land-to-water facility at Whitestone Harbor would require less fill in the tidelands, but would result in a similar—although smaller—problem: with less area to collect surface runoff, less water would need to be treated.

The Deep Bay and Little Hamilton Bay facilities are designed to use a combination of pile structure and rockfill. Rockfill is generally cheaper to construct but removes marine habitat from production and may physically interfere with fish movements and currents. The combination design offers the best features of the pile face without the additional cost of a totally pile-supported structure.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 mile = 1.609 kilometers
1 acre = 0.4 hectare
1 ton (2000 pounds) = 907.2 kilograms

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The volume of timber harvested in southeast Alaska betweeen 1909 and 1983 was 14,689 million board feet; nearly all was transported on water to various destinations for processing. In 1971 there were 69 active log transfer and storage facilities and 38 raft collecting and storage facilities in southeast Alaska. In 1983 there were 90 log transfer sites, 49 log storage sites, 228 sites proposed for log transfer development, and 12 sites proposed for log storage development. We calculated that there were 176 acres of estuarine habitat covered by bark from 90 log transfer sites in 1982. Additional habitat was covered by bark at log storage sites. In 1981, approximately 1,388 acres would have been covered by log rafts at some time. The statistics for numbers of log transfer and storage sites no longer in use are too incomplete for use in estimating bark coverage.

The options for handling logs at a saltwater facility are land-to-water (rafting), land-to-vessel (barging or shipping), and land-to-water-to-ship (loading barge or ship from water). The A-frame has been the preferred device for log transfer because of operating economy and availability. Other transfer methods include chain conveyors, "beaver slide" ramps, and rockfill ramps.

Keywords: Log transfer, log storage, Alaska (southeast), southeast Alaska.

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DFSIM WITH ECONOMICS: A Financial Analysis Option for the DFSIM Douglas-Fir Simulator

Roger D. Fight, Judith M. Chittester, and Gary W. Clendenen

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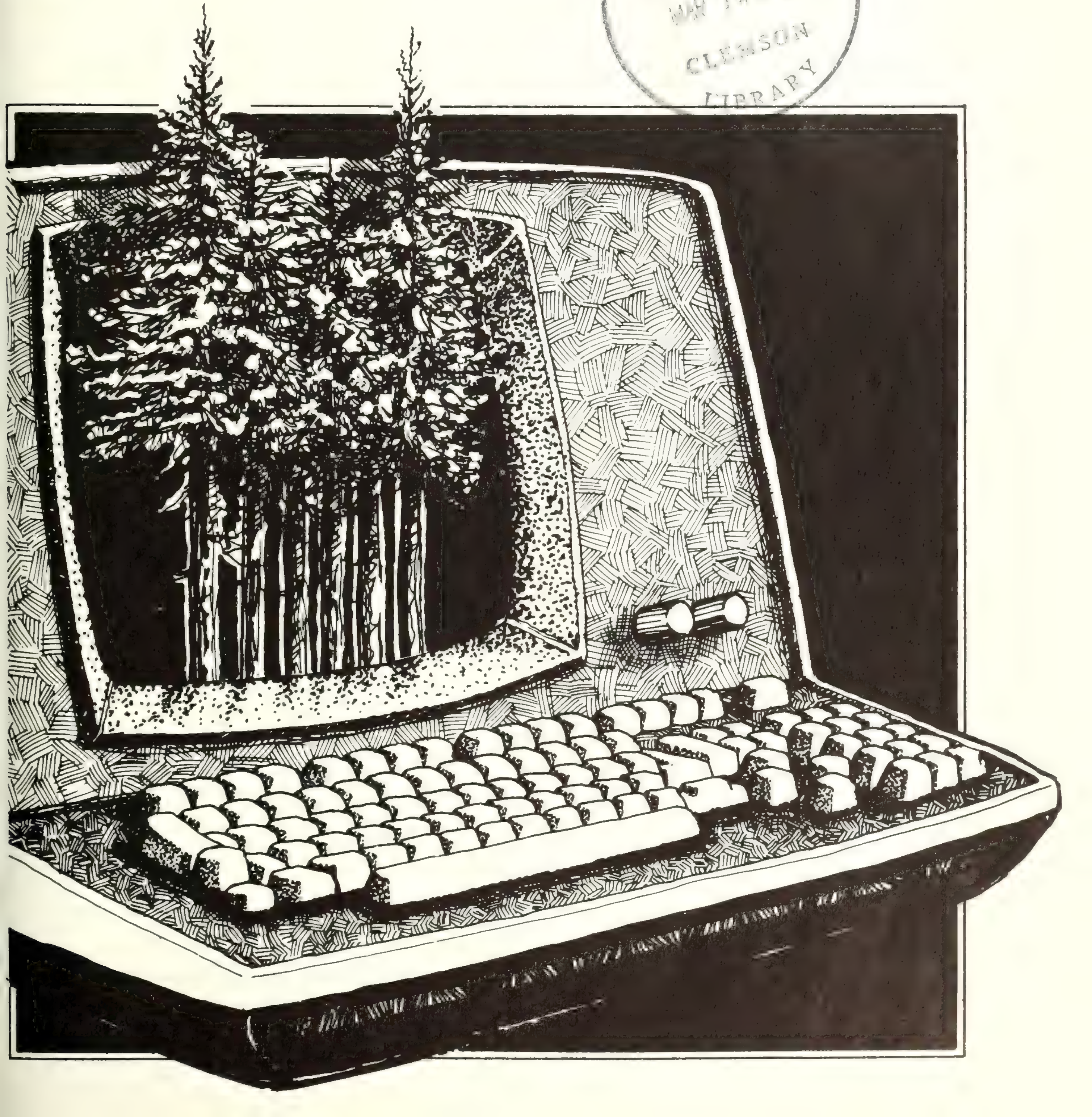

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Abstract

Fight, Roger D.; Chittester, Judith M.; Clendenen, Gary W. DFSIM WITH ECONOMICS: A financial analysis option for the DFSIM Douglas-fir simulator. Gen. Tech. Rep. PNW-175. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 22 p.

A modified version of the DFSIM Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) growth and yield simulator, DFSIM WITH ECONOMICS, now has an economics option that allows the user to estimate present net worth at the same time a silvicultural regime is simulated. If desired, the economics option will apply a volume adjustment multiplier in yields used in the analysis to reflect application of small-plot research results to average operating conditions or to account for genetics or other local conditions. It can also account for salvage of mortality. Prices can be entered as a table of values or as an equation that can vary with diameter. Logging costs can be entered as a table or can be generated internally for a short-span cable system. Logging costs can vary by diameter and volume harvested. Other harvest-related costs can be included on a per acre basis and also on a unit volume basis. Prices and costs can be trended using an annual percentage rate of change that is applied for a 50-year period.

An interactive program, SIMIN2 WITH ECONOMICS, can be used to prepare the input data in the format required by the DFSIM WITH ECONOMICS program. Both programs are available from the Biometrics Group, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, P.O. Box 3890, Portland, Oregon 97208.

Keywords: Simulation, financial analysis, DFSIM. Douglas-fir (coast).

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Introduction

The Douglas-fir stand simulator (DFSIM) for coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) (Curtis and others 1981) is now widely used by foresters and silviculturists in forest management planning. The published version (1.0) of the simulator does not have the capability to provide financial analysis of the regimes that are simulated. A user desiring financial information must take the DFSIM results and prepare data input for a separate financial analysis computer program.

A financial analysis option has been added to the DFSIM stand simulator. With this new version (1.1) of DFSIM (DFSIM WITH ECONOMICS) the user can run the program in batch mode with the same input as for the original program, and the output will be identical to that from the original program; or the user can invoke the financial analysis option, supply the additional input required, and the output will include financial results.

The input file needed to run DFSIM WITH ECONOMICS can be prepared by use of an interactive program designed to assist the user in preparing the input file. Both programs are available from the Biometrics Group of the Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, P.O. Box 3890, Portland, Oregon 97208.

We have written this report as an amendment to the original DFSIM user's guide (Curtis and others 1981) and assume that the reader is familiar with that publication or has access to it. Definitions, abbreviations, and variable names used in that publication are used here with no further description. The next section of the report describes and illustrates the financial results, and the following section describes the assumptions used and the limitations of the financial analysis option. We then describe and illustrate the input data required for use of the financial analysis option.

Results

Financial analysis results will be consistent with and printed on only one of the DFSIM output tables. They will be printed only if that table is requested. Figure 1 shows the economics output on the table of trees 5.6 inches plus; cubic units are to a 4-inch top. At each harvest the following values are reported:

TRUE DBH The arithmetic mean diameter of the cut trees are opposed to the quadratic mean diameter that is reported elsewhere. It is used because the logging cost equations built into the model are based on arithmetic mean diameter. Two-digit precision is shown only for verifying logging cost calculations.

VOL Volume cut in thousands (M) of the specified volume units. The volume will differ from that reported elsewhere when the mortality salvage option or the volume adjustment multiplier option is used.

POND VALUE Value per thousand volume units of logs delivered to the mill.

LOG COST Stump-to-truck logging cost per thousand volume units.

HAUL COST Cost per thousand volume units of hauling from harvest area to the mill.

OTHER COST All other costs associated with harvesting converted to a cost per thousand volume units.

NET REVENUE Pond value minus the sum of log cost, haul cost, and other cost.

DISC NET REVENUE Net revenue per thousand volume units discounted from time of harvest to time at start of the simulation. This period will equal stand age except when a simulation is for an existing stand. For existing stands the value will be discounted to the age of the existing stand at the start of the simulation.

PNW1 Cumulated present net worth from the beginning of the simulation through the current harvest.

PNW2 Cumulated present net worth from the beginning of the second rotation through the age of the current harvest. This will differ from PNW1 when values are trended or when a one-time cost at time of the first commercial entry is used. This value is not reported for existing stands.

%VOL DEAD Percent of volume harvested coming from salvage of mortality.

After the final harvest the following additional values are reported:

SOIL EXPECTATION VALUE This is the present net worth of an infinite series of rotations. It uses the same regime for each rotation and the costs and revenues that have been adjusted by use of the price and cost trends that are specified. It is not reported for existing stands. This value approaches infinity (and becomes meaningless) as the interest rate approaches zero.

MEAN ANNUAL HARVEST This is the cumulative volume including salvage volume divided by the stand age at final harvest.

PERCENT OF VOLUME FROM MORTALITY SALVAGE This is the percent of cumulative volume coming from salvage of mortality.

Figure 1.—Sample DFSIM WITH ECONOMICS output.

```
                         D F S I M   VERSION 1.1                      PAGE  1
                       EXAMPLE DFSIM WITH ECONOMICS
                            MANAGED YIELD TABLE
                              FOR DOUGLAS-FIR
                              1.6 INCHES PLUS

                       SITE INDEX =  125. (50 YEARS BH)

                  STAND ORIGIN --- NATURAL.
                  STAND WILL BE PRECOMMERCIALLY THINNED AT AGE  11. TO  300. TREES
                  PER ACRE.
                  FIRST COMMERCIAL THINNING IS WANTED AT AGE  30.
                  THE NUMBER OF COMMERCIAL THINNINGS SPECIFIED IS  4.
                  COMMERCIAL THINNINGS ARE SCHEDULED AT THE FOLLOWING AGES
                     30.   40.   54.   70.
                  THE SCHEDULED AGE AT THE HARVEST CUT IS  80.
                  THE AVERAGE DIAMETER OF ALL CUT TREES AT COMMERCIAL THINNINGS
                  MUST BE AT LEAST  8.00 INCHES.
                  THE BASAL AREA CUT AT EACH COMMERCIAL THINNING MUST BE
                  AT LEAST 20. SQUARE FEET PER ACRE.
                  THE BASAL AREA PER ACRE OF ALL TREES 5.6 INCHES PLUS MUST BE
                  AT LEAST  100.0 SQUARE FEET BEFORE THE FIRST COMMERCIAL
                  THINNING CAN OCCUR.


TOT  BH          LOREY          BASAL  TREES    CVTS    CAI  *MAI CVTS*  **MAI CV4**
AGE AGE   HT40    HT      DBH AREA/A    PER     PER    NET  GROSS  NET  ****NET****
YRS YRS   FEET   FEET    INCH  SQ FT   ACRE    ACRE   CVTS  1.6+  1.6+  5.6+  7.6+

 30  23

BEFORE    70.7   64.9    9.70  148.5    289.   3952.  325.  133.  132.  120.  113.
CUT                      9.14   35.5     78.    932.
RESIDUAL  70.7   65.4    9.90  113.1    212.   3020.

SUM CUTS                        35.5     78.    932.
SUM MORTALITY                    1.2     11.     29.

 40  33

BEFORE    94.2   87.5   12.82  182.3    204.   6379.  335.  185.  183.  172.  169.
CUT                     10.84   45.6     71.   1643.
RESIDUAL  94.2   88.0   13.76  136.7    132.   4736.

SUM CUTS                        81.1    149.   2575.
SUM MORTALITY                    3.0     19.     90.

 54  47

BEFORE   120.2  113.3   17.46  209.9    126.   9064.  297.  220.  216.  205.  203.
CUT                     14.19   41.5     38.   1900.
RESIDUAL 120.2  113.7   18.68  168.3     88.   7164.
```

Figure 1.—Continued

```
                         D F S I M   VERSION 1.1                      PAGE  2
                        EXAMPLE DFSIM WITH ECONOMICS
                           MANAGED YIELD TABLE
                             FOR DOUGLAS-FIR
                             1.6 INCHES PLUS

                        SITE INDEX =  125. (50 YEARS BH)

TOT  BH          LOREY         BASAL  TREES   CVTS   CAI  *MAI CVTS*  **MAI CV4**
AGE AGE   HT40    HT     DBH AREA/A   PER     PER   NET  GROSS  NET  ****NET****
YRS YRS   FEET   FEET   INCH  SQ FT   ACRE   ACRE  CVTS  1.6+  1.6+  5.6+  7.6+

SUM CUTS                       122.6   187.  4475.
SUM MORTALITY                    6.1    25.   217.

 70  63

BEFORE   143.1 136.6  22.63  238.5    85. 11709.  266.  237.  231.  220.  219.
CUT                   18.82   38.5    20.  2025.
RESIDUAL 143.1 136.8  23.67  200.0    65.  9684.

SUM CUTS                       161.1   207.  6500.
SUM MORTALITY                   10.4    28.   422.

 80  73

HARVEST  154.7 148.8  26.23  241.5    64. 12349.  254.  242.  236.  225.  223.

SUM CUTS                       402.6   271. 18849.
SUM MORTALITY                   12.9    29.   549.
```

Figure 1.—Continued

```
                    D F S I M   VERSION 1.1                    PAGE  3

ECONOMICS TABLES UNITS:                                CV4
   COSTS AND REVENUES ARE IN $ PER 1000
   PRESENT NET WORTHS ARE IN $ PER ACRE

SALVAGE OF MORTALITY OPTION                            YES
THE FOLLOWING TABLE OF POND VALUES HAS BEEN ENTERED:
DBH        6.0   24.0     0.0     0.0     0.0     0.0     0.0     0.0
PONDVL   860.0 1490.0     0.0     0.0     0.0     0.0     0.0     0.0

THE FOLLOWING TABLE OF LOGGING COST VALUES HAS BEEN ENTERED:
                  INTERMEDIATE LOGGING COST
DIAM.             VOLUME (M UNITS)
       .500  1.000  1.500  2.000  5.000 10.000
  6.0  723.   663.   630.   606.   546.   535.
  8.0  608.   549.   518.   497.   445.   435.
 10.0  519.   462.   433.   413.   368.   359.
 12.0  448.   392.   364.   345.   307.   298.
 14.0  391.   337.   309.   291.   257.   249.
 16.0  347.   293.   266.   249.   218.   210.
 18.0  433.   332.   289.   264.   220.   208.
 20.0  397.   296.   254.   230.   189.   177.
 22.0  375.   274.   233.   209.   170.   158.
 24.0  366.   266.   225.   201.   162.   151.

 THE ABOVE TABLE OF LOGGING COST VALUES WILL BE USED FOR FINAL HARVEST.

THE FOLLOWING VALUES HAVE BEEN INPUT:                VALUE  COST TREND
                                                     -----  ----------

   VOLUME ADJUSTMENT MULTIPLIER                        .90
   INTEREST RATE                                      4.0
   PRICE TREND                                        1.5
   REGENERATION COST PER ACRE                       200.0        1.0
   PRECOMMERCIAL THIN COST PER ACRE                 100.0        1.0
   LOGGING COST MULTIPLIER                            1.20       0.0
   OTHER PER ACRE THIN COST                          50.0        1.0
   OTHER PER M UNIT VOLUME THIN COST                  0.0        0.0
   OTHER PER ACRE FINAL HARVEST COST                 30.0        1.0
   OTHER PER M UNIT VOLUME FINAL HARVEST COST         0.0        0.0
   HAULING COST PER M UNIT VOLUME                   150.0        0.0
   FIRST HARVEST ROAD COST PER ACRE                   0.0        0.0
```

Figure 1.—Continued

```
                        D F S I M   VERSION 1.1                        PAGE  4
                      EXAMPLE DFSIM WITH ECONOMICS
                          MANAGED YIELD TABLE
                            FOR DOUGLAS-FIR
                            5.6 INCHES PLUS

                      SITE INDEX = 125. (50 YEARS BH)

                     BASAL AREA  TREES   TOTAL     CUBIC FEET
               DBH    PER ACRE    PER  CUBIC FEET   PER ACRE
              INCHES  SQ. FT.     ACRE  PER ACRE   4-INCH TOP
TOTAL AGE  30.

BEFORE         10.3    145.0     249.     3881.       3600.
CUT             9.4     35.2      74.      916.        835.
RESIDUAL       10.7    109.8     176.     2965.       2765.

SUM CUTS                35.2      74.      916.        835.
SUM MORTALITY                               10.

  TRUE    VOL   POND    LOG  HAUL  OTHER    NET    DISC NET    PNW1    PNW2  %VOL
  DBH           VALUE   COST COST   COST  REVENUE  REVENUE                   DEAD

  8.94    .75  1505.   644.  150.    90.    621.     191.    -163.   -176.   0.0


TOTAL AGE  40.

BEFORE         12.9    182.0     200.     6364.       6042.
CUT            11.0     45.5      69.     1635.       1530.
RESIDUAL       13.8    136.5     131.     4729.       4512.

SUM CUTS                80.7     143.     2552.       2364.
SUM MORTALITY                               47.

  TRUE    VOL   POND    LOG  HAUL  OTHER    NET    DISC NET    PNW1    PNW2  %VOL
  DBH           VALUE   COST COST   COST  REVENUE  REVENUE                   DEAD

 10.52   1.38  1847.   507.  150.    54.   1136.     237.     163.    233.   0.0


TOTAL AGE  54.

BEFORE         17.5    209.9     126.     9064.       8702.
CUT            14.2     41.5      38.     1900.       1814.
RESIDUAL       18.7    168.3      88.     7164.       6887.

SUM CUTS               122.2     181.     4452.       4178.
```

Figure 1.—Continued

```
                          D F S I M   VERSION 1.1                  PAGE  5
                       EXAMPLE DFSIM WITH ECONOMICS
                           MANAGED YIELD TABLE
                             FOR DOUGLAS-FIR
                             5.6 INCHES PLUS

                       SITE INDEX = 125. (50 YEARS BH)

                         BASAL AREA  TREES    TOTAL    CUBIC FEET
                  DBH     PER ACRE    PER   CUBIC FEET  PER ACRE
                 INCHES   SQ. FT.     ACRE   PER ACRE  4-INCH TOP
SUM MORTALITY                                   156.

  TRUE     VOL   POND    LOG   HAUL  OTHER    NET    DISC NET    PNW1     PNW2  %VOL
  DBH            VALUE   COST  COST   COST  REVENUE  REVENUE                    DEAD

 13.65    1.66  2374.    375.  150.    50.   1800.     216.      522.     593.   1.6


TOTAL AGE  70.

BEFORE            22.6    238.5       85.   11709.      11241.
CUT               18.8     38.5       20.    2025.       1944.
RESIDUAL          23.7    200.0       65.    9684.       9296.

SUM CUTS                  160.7      201.    6477.       6123.
SUM MORTALITY                                 362.

  TRUE     VOL   POND    LOG   HAUL  OTHER    NET    DISC NET    PNW1     PNW2  %VOL
  DBH            VALUE   COST  COST   COST  REVENUE  REVENUE                    DEAD

 18.21    1.80  2710.    324.  150.    46.   2190.     141.      775.     846.   2.8


TOTAL AGE  80.

HARVEST           26.2    241.5       64.   12349.      11855.

SUM CUTS                  402.3      265.   18826.      17978.
SUM MORTALITY                                 488.

  TRUE     VOL   POND    LOG   HAUL  OTHER    NET    DISC NET    PNW1     PNW2  %VOL
  DBH            VALUE   COST  COST   COST  REVENUE  REVENUE                    DEAD

 25.55   10.72  3137.    181.  150.     5.   2801.     122.     2078.    2148.    .4


SOIL EXPECTATION VALUE                         2175.
MEAN ANNUAL HARVEST                             204.
PERCENT OF VOLUME FROM MORTALITY SALVAGE          .8
```

Assumptions and Limitations

The user may choose to do the financial analysis in any of the four optional units offered in DFSIM. If CV4 units are selected the results will appear only if the table for trees 5.6 inches plus is requested. If CV6, IV6, or SV6 units are selected, the results will appear only if the table for trees 7.6 inches plus (not shown in this publication) is requested. The economic data used in the financial analysis will be consistent with only one unit of measure. The financial analysis must be done in those units, and the appropriate table must be requested.

Price and cost trends can be specified. The rate specified must be an annual percentage change. That rate will be applied for 50 years. After the 50th year all prices and costs remain constant at the value computed for the 50th year.

If the user does not provide a table of logging costs, the program will generate them from a subroutine developed by Sessions (1979). This subroutine was developed for a 600-ft cable system. Costs are in 1978 dollars. The costs are valid only for CV4 units. This cost subroutine is included primarily to allow the user to see the effect that realistic logging cost relationships have on financial results. For actual application the user must supply logging cost tables that are specific to the conditions being simulated.

The user can specify costs for relevant combinations of average diameter of trees cut and volume per acre removed in the tables of logging costs. Two tables can be used; one for thinnings and one for final harvest. The values used for a particular harvest are determined by a linear interpolation across diameter and volume per acre.

The mortality salvage option is a rough approximation applied to a number (annual mortality) which is based on a weak relationship (Curtis and others 1981, p. 71). If salvage of mortality is ignored in the financial calculations, the implicit assumption is that there is no salvage of mortality or that it has a zero net value. The mortality salvage option is probably an improvement when there is significant anticipated mortality.

Mortality salvage trees are assumed to lose diameter at the following rates:

Year	DBH Loss
0	0
1	2.0
2	4.0
3	5.5
4	6.8
5	8.0
6+	Total loss

These rates are based on Kimmey and Furniss (1943).

Volumes for mortality trees are based on trees of the reduced diameter. The salvage volume for a tree is set to zero if the basal area reduction exceeds 50 percent or if the reduced diameter is less than the user specified minimum merchantable diameter. The salvageable mortality volume is added to the live volume for all further calculations when the mortality salvage option is used.

Results from DFSIM reflect the volume growth of trees on research plots that are of uniform stocking and have not had significant losses from natural or human causes. It is generally accepted that yields in operational situations will be somewhat less than yields predicted from research plots because of nonuniformity of stocking and natural losses not accounted for. Other factors such as genetically improved planting stock may result in expectations of yields exceeding those simulated by DFSIM. The user can make a net adjustment for all relevant factors by specifying a volume adjustment multiplier. All volumes will be multiplied by the volume adjustment multiplier, and the adjusted volumes will be used in all financial calculations and will be reported in the financial output.

Format and Explanation of Input Data

Program SIMIN2 developed by Stephen C. Gaston of International Paper Company assists in the preparation of the input file to run DFSIM.[1] We have modified that program to assist in the preparation of the input file to run DFSIM WITH ECONOMICS. It is written in FORTRAN V for the CDC 6500. The modified program (SIMIN2 WITH ECONOMICS) is available (with permission of International Paper Company) on request along with the modified DFSIM (DFSIM WITH ECONOMICS).

Program SIMIN2 WITH ECONOMICS is an interactive program that sets up a control file for DFSIM WITH ECONOMICS. The program will "step" the user through all DFSIM WITH ECONOMICS options automatically. SIMIN2 WITH ECONOMICS questions are self-explanatory. The program can be used to set up several simulations at a time with timesaving "repeat previous simulation" questions whenever practicable. Variable names are as defined in DFSIM. If a logging cost table input file is used, it must be designated as logical unit 13 prior to executing SIMIN2 WITH ECONOMICS. Logical unit 13 (table of logging costs) for the example in figure 1 is included in appendix 1. More than one table can appear on logical unit 13; each must have a unique five character name in columns 1-5 on the card preceding the table (for example, TAB01 in appendix 1). The rows of the table, read in free format, are the same as DFSIM WITH ECONOMICS card types 15 and 16. The control file is output on logical unit 3.

Appendix 2 shows an actual interactive session with SIMIN2 WITH ECONOMICS for the example in figure 1. Each prompt is followed by a response selected by the user. Appendix 3 is a form titled "Input Form for DFSIM WITH ECONOMICS Short Control File." This form can be used to document the input data for a series of simulations; it speeds the process of responding to the SIMIN2 WITH ECONOMICS queries. Not all items on the form are required for every simulation. The ones requested depend on the options selected. The output file, logical unit 3, from SIMIN2 WITH ECONOMICS is shown in appendix 4. This output file is the logical unit 5 control file for DFSIM WITH ECONOMICS. The various subroutines and functions that have been added to the DFSIM program are listed in appendix 5 along with a brief statement of the operation performed by each.

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[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

If the interactive program is not used to prepare the input data, logical unit 5 can be prepared from the description that follows.

Additions to DFSIM master control card:

Variable name	Format	Columns	Contain	Explanation
ECO	I1	76	0 or b	No financial evaluation option.
			1	Financial evaluation option.
Blank	4x	77-80	bbbb	Blank.

Economics Master Card 1 (Card Type 10).—This economics master card is the first of two master cards used to specify the financial evaluation option. All economics control cards follow DFSIM card type 8 (if used) and precede DFSIM card type 9 (if used). Options selected determine the units for the economics tables, how the pond value prices and the logging costs are to be calculated, and whether the mortality option and the volume adjustment multiplier are used.

Variable name	Format	Columns	Contain	Explanation
Blank	1x	1	b	Blank.
EUNITS	A3	2-4	AAA	Units for economics tables—specify one of the following: CV4,CV6,IV6,SV6.
Blank	1x	5	b	Blank.
PONTAB	I2	6-7	0 or b	No pond value price table. (Coefficients for the pond value equation are given.)
			XX	Number of DBH values in the table (up to 8).
Blank	1x	8	b	Blank.
COSTAB	I1	9	0 or b	No logging cost table is provided. (Program equations are used.) Note: Program equations are valid for CV4 units only.
			1	Logging cost table provided.
			2	Separate final harvest logging cost table provided.
Blank	3x	10-12	b	Blank.
LDI	I2	13-14	0 or b	None.
			XX	Number of rows (DBH) in intermediate logging cost table (up to 12).
Blank	1x	15	b	Blank.
LVI	I2	16-17	0 or b	None.
			XX	Number of columns (volumes) in intermediate logging cost table (up to 12).

Variable name	Format	Columns	Contain	Explanation
Blank	1x	18	b	Blank.
LDF	I2	19-20	0 or b	None.
			XX	Number of rows (DBH) in final harvest logging cost table (up to 12).
Blank	1x	21	b	Blank.
LVF	I2	22-23	0 or b	None.
			XX	Number of columns (volumes) in final harvest logging cost table (up to 12).
Blank	1x	24	b	Blank.
A	F14.8	25-38	0 or b	Pond value price equation not used. (Pond value price table provided.)
			XX. . .X	First coefficient for pond value price equation.
Blank	1x	39	b	Blank.
B	F14.8	40-53	0 or b	None.
			XX. . .X	Second coefficient for pond value price equation.
Blank	1x	54	b	Blank.
C	F14.8	55-68	0 or b	None.
			XX. . .X	Third coefficient for pond value price equation.
Blank	1x	69	b	Blank.
IMORT	I1	70	0 or b	No mortality option.
			1	Mortality option.
Blank	1x	71	b	Blank.
VAM	F4.2	72-75	XXXX	Volume adjustment multiplier.
Blank	5x	76-80	bbbbb	Blank.

Economics Master Card 2 (Card Type 11).—This economics master card is the second of two master cards used to specify the financial evaluation option. Selections determine the interest rate, the logging cost multiplier, per acre costs, other costs, and whether price and cost trends are provided.

Variable name	Format	Columns	Contain	Explanation
Blank	1x	1	b	Blank.
R	F4.1	2-5	XXXX	Interest rate.
Blank	1x	6	b	Blank.
REGENC	F5.0	7-11	XXXXX	Regeneration cost per acre.
Blank	1x	12	b	Blank.
PCTC	F5.0	13-17	XXXXX	Precommercial thinning cost per acre.
Blank	1x	18	b	Blank.
FC	F5.0	19-23	0 or b	No fertilization selected.
			XXXXX	Number of fertilization rate-cost pairs provided. Must be one pair for each different fe tilization rate provided on DFSIM card type 7. A maximum of 9 rate-cost pairs are allowed.
Blank	1x	24	b	Blank.
LCM	F4.2	25-28	XXXX	Logging cost multiplier.
Blank	1x	29	b	Blank.
FHRC	F5.0	30-34	XXXXX	First harvest road cost per acre
Blank	1x	35	b	Blank.
OATC	F5.0	36-40	XXXXX	Other per acre thinning cost.
Blank	1x	41	b	Blank.
OVTC	F5.0	42-46	XXXXX	Other per M unit volume thinning cost.
Blank	1x	47	b	Blank.
OAHC	F5.0	48-52	XXXXX	Other per acre final harvest cos
Blank	1x	53	b	Blank.
OVHC	F5.0	54-58	XXXXX	Other per M unit volume final harvest cost.
Blank	1x	59	b	Blank.
HC	F5.0	60-64	XXXXX	Hauling cost per M unit volume
Blank	1x	65	b	Blank.
INFLAT	I1	66	0 or b	No price or cost trends.
			1	Price or cost trends.
Blank	14x	67-80	bb. . .b	Blank.

Trend Card (Card Type 12).—The trend card is used if the trend parameter INFLAT[11,12] on the second economics master card, column 66, is coded 1. All trends are specified as annual percentage rates of change and apply to a 50-year period.

Variable name	Format	Columns	Contain	Explanation
Blank	1x	1	b	Blank.
PVI	F4.1	2-5	XXXX	Pond value (price) trend.
Blank	1x	6	b	Blank.
RCI	F4.1	7-10	XXXX	Regeneration cost trend.
Blank	1x	11	b	Blank.
PCTCI	F4.1	12-15	XXXX	Precommercial thinning cost trend.
Blank	1x	16	b	Blank.
FCI	F4.1	17-20	XXXX	Fertilization cost trend.
Blank	1x	21	b	Blank.
LCI	F4.1	22-25	XXXX	Logging cost trend.
Blank	1x	26	b	Blank.
FHRCI	F4.1	27-30	XXXX	First harvest road cost trend.
Blank	1x	31	b	Blank.
OAHCI	F4.1	32-35	XXXX	Other per acre harvest cost trend.
Blank	1x	36	b	Blank.
OVHCI	F4.1	37-40	XXXX	Other per M unit volume harvest cost trend.
Blank	1x	41	b	Blank.
HCI	F4.1	42-45	XXXX	Hauling cost trend.
Blank	35x	46-80	bb. . .b	Blank.

Pond Value Card 1 (Card Type 13).—This pond value card is the first of two cards used to specify the pond value price table. It is used if the pond value price parameter PONTAB[10,2] on the first economics master card, columns 6-7, is coded with the number of DBH (rows) in the pond value price table. Up to eight DBH values can be input.

Variable name	Format	Columns	Contain	Explanation
Blank	1x	1	b	Blank.
PONDVL(1,1)	F4.1	2-5	XXXX	DBH value for first entry in the table.
Blank	1x	6	b	Blank.
PONDVL(2,1)	F4.1	7-10	XXXX	DBH value for second entry in the table.
PONDVL(3-8,1)	6(1x,F4.1)	11-40	XXXX	DBH values for up to six additional entries.
Blank	40x	41-80	bb. . .b	Blank.

Pond Value Card 2 (Card Type 14).—This pond value card is the second of two cards used to specify the pond value price table. It is used if the pond value price parameter PONTAB[10,2] on the first economics master card, columns 6-7, is coded with the number of DBH values in the pond value price table. One price associated with each DBH value given on the first pond value card must be input. Up to eight prices can be input.

Variable name	Format	Columns	Contain	Explanation
Blank	1x	1	b	Blank.
PONDVL(1,2)	F5.0	2-6	XXXXX	Price associated with first DBH value.
Blank	1x	7	b	Blank.
PONDVL(2,2)	F5.0	8-12	XXXXX	Price associated with second DBH value.
PONDVL(3-8,2)	6(1x,F5.0)	13-48	XXXXX	Price associated with remaining DBH values.
Blank	32x	49-80	bb. . .b	Blank.

Logging Cost Volumes Card (Card Type 15).—This logging cost volumes card is used if the logging cost parameter COSTAB[10,3] on the first economics master card, column 9, is coded 1 or 2. These volumes in M units can be thought of as the column headings for the logging cost table. Up to 12 volumes may be entered. If COSTAB[10,3] is coded 1 these volumes will be used at both intermediate cutting times and at the final harvest. In this case the number of volumes entered is the value of the column number parameter for the intermediate logging cost table LVI[10,5] on the first economics master card, columns 16-17. If COSTAB[10,3] is coded 2 a second full set of logging cost cards must be entered. In the latter case the number of volumes entered for the second set is the value of the column number parameter for the final logging table LVF[10,7] on the first economics master card, columns 22-23.

Variable name	Format	Columns	Contain	Explanation
Blank	1x	1-5	bbbbb	Blank.
LOGVI(1)	F6.2	6-11	XXXXXX	First volume in M units.
LOGVI(2)	F6.2	12-17	XXXXXX	Second volume in M units.
LOGVI(3-12)	10F6.2	18-77	XXXXXX	Volumes for up to 10 additional entries.
Blank	3x	78-80	bbb	Blank.

Logging Cost DBH and Costs Cards (Card Type 16).—These logging cost DBH and costs cards are used in conjunction with the logging cost volumes card to specify the logging cost table. Include as many of these cards as the value of the row number parameter for the intermediate logging cost table, LDI[10,4], columns 13-14, on the first economics master card; for the final logging cost table, LDF[10,6], columns 19-20.

Variable name	Format	Columns	Contain	Explanation
Blank	1x	1	b	Blank.
LOGDI(1)*	F4.1	2-5	XXXX	Row I DBH.
LOGCI(I,1)*	F6.0	6-11	XXXXXX	Cost associated with first column volume in row I.
LOGCI(I,2)	F6.0	12-17	XXXXXX	Cost associated with second column volume in row I.
LOGCI(I,3-12)	10F6.0	18-77	XXXXXX	Costs associated with remaining volumes in row I.
Blank	3x	78-80	bb. . .b	Blank.

*If COSTAB[10,3] on the first economics master control card, column 9, is coded 2, the variable names are LOGDF and LOGCF for the second set of logging cost cards.

Fertilization Rate and Cost Card (Card Type 17).—This fertilization rate and cost card is included if the economics fertilization parameter FC[11,4] on the second economics master card, columns 19-23, is coded with the number of fertilization rate-cost pairs. There must be a rate and cost for every rate (quantity) specified on DFSIM card type 7. They are mandatory if a DFSIM card type 7 card is included. Up to nine rate-cost pairs may be entered.

Variable name	Format	Columns	Contain	Explanation
Blank	1x	1	b	Blank.
CNIT(1,1)	F3.0	2-4	XXX	First rate (pounds of nitrogen per acre).
CNIT(1,2)	F4.0	5-8	XXXX	Cost for first rate.
CNIT(2-9,1), CNIT(2-9,2)	8(1x,F3.0, F4.0)	9-72	XXX, XXXX	Rates and costs associated with remaining quantities of nitrogen.
Blank	8x	73-80	bb. . .b	Blank.

Metric Equivalents

1 inch (in) = 2.54 centimeters
1 foot (ft) = 0.3048 meter
1 square foot (ft^2) = 0.09290 square meter
1 square foot per acre (ft^2/acre) = 0.2296 square meter per hectare
1 cubic foot per acre (ft^3/per acre) = 0.06997 cubic meter per hectare

Literature Cited

Curtis, Robert O.; Clendenen, Gary W.; DeMars, Donald J. A new stand simulator for coast Douglas-fir: DFSIM user's guide. Gen. Tech. Rep. PNW-128. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1981.** 79 p.

Kimmey, J. W.; Furniss, R. L. Deterioration of fire-killed Douglas-fir. Tech. Bull. 851. Washington, DC: U.S. Department of Agriculture; **1943.** 61 p.

Sessions, Julian. Effects of harvesting technology upon optimal stocking regimes of forest stands in mountainous terrain. Corvallis, OR: Oregon State University; **1979.** 259 p. Ph. D. dissertation.

Appendix 1

Logical Unit 13 Example

```
TAB01

    0.5  1.0  1.5  2.0  5.0  10.
 6  723  663  630  606  546  535
 8  608  549  518  497  445  435
10  519  462  433  413  368  359
12  448  392  364  345  307  298
14  391  337  309  291  257  249
16  347  293  266  249  218  210
18  433  332  289  264  220  208
20  397  296  254  230  189  177
22  375  274  233  209  170  158
24  366  266  225  201  162  151
```

Appendix 2
Sample SIMIN2 Run

```
THIS INTERACTIVE PROGRAM GENERATES THE CONTROL FILE INPUT TO RUN DFSIM

QUESTIONS CONCERNING THIS PROGRAM MAY BE DIRECTED TO THE U.S.FOREST SERVICE,
PNW FOREST AND RANGE EXPERIMENT STATION, BIOMETRICS UNIT (503) 231-2063
ANY QUESTIONS ABOUT ECONOMICS DATA SHOULD BE DIRECTED TO:
ROGER FIGHT - PNW (503) 231-2086.




THIS PROGRAM REQUESTS USER SPECIFIED INPUT TO INITIALIZE A DFSIM RUN
PLEASE ENTER INTEGER VALUES (UNLESS OTHERWISE SPECIFIED) IN THE ORDER
REQUESTED, SEPARATED BY COMMAS, AND FOLLOWED BY A CARRIAGE RETURN.
IF YES OR NO IS REQUIRED, DO NOT INSERT LEADING BLANKS.

ENTER A TITLE FOR THIS DFSIM RUN (UP TO 80 COLUMNS)
                          EXAMPLE DFSIM WITH ECONOMICS

WOULD YOU PREFER A LIMITED (SHORTER) CONTROL FILE ? Y

ENTER THE FOLLOWING VARIABLES:
    SITE INDEX (50 YR),
    STAND ORIGIN (0=NATURAL OR SEEDED, 1=PLANTED),
    AGE OF PRECOMMERCIAL THINNING (0=NO PCT),
    STAND OPTION (0=REGIONAL AVERAGE, 1=USER SUPPLIED STAND CONDITIONS),
    COMMERCIAL THINNING (0=NO CT, 1=CT OPTION),
    FERTILIZATION (0=NO FERT, 1=FERT DURING EACH CT, 2=FERT AT USER
         SPECIFIED AGES) 125,0,11,0,1,0

ENTER THE TOTAL STAND TPA AFTER PCT 300

ENTER THE NUMBER OF COMMERCIAL THINNINGS (UP TO 9) 4

ENTER A TOTAL AGE FOR EACH COMMERCIAL THIN 30,40,54,70

SELECT NONE, ONE, OR TWO OF THE FOLLOWING CT OPTIONS:
    USER SUPPLIED D/D RATIO FOR EACH CT
         0=NO
         1=USER SPECIFICATIONS BETWEEN .80 & 1.25
         2=UNRESTRICTED USER SPECIFICATIONS
    USER SUPPLIED RESIDUAL SBA FOR EACH CT
         0=NO
         1=YES
    USER SUPPLIED RESIDUAL TPA FOR EACH CT
         0=NO
         1=YES

  NOTE: A VALUE MUST BE ENTERED FOR EACH OPTION 0,0,0

ENTER THE FOLLOWING FOUR VARIABLES:
    TOTAL STAND AGE FOR EARLIEST POSSIBLE CT
    MINIMUM SBA (TREES > 5.5 DBH) FOR EARLIEST POSSIBLE CT (0=100)
    MINIMUM QMD(NEAREST .1) OF TREES REMOVED (0=8.0)
    MINIMUM BASAL AREA TO BE REMOVED (0=20) 0,0,0,0

ENTER THE ROTATION LENGTH:
    ROTATION AGE (0=ROTATION HEIGHT SUPPLIED)
    AND, HEIGHT AT FINAL HARVEST (0=ROTATION AGE SUPPLIED) 80,0
```

```
ENTER THREE OUTPUT PARAMETERS:
    OUTPUT TABLE TYPES
         0=TREES > 1.5 DBH
         1=ALL TYPES (TREES > 1.5, 5.5, 7.5 DBH)
         2=TWO TYPES (TREES > 1.5 AND 5.5 DBH)
         3=TWO TYPES (TREES > 1.5 AND 7.5 DBH)
    OUTPUT TIMING
         0=OUTPUT TABLES AT CUTTING AGES
         1=OUTPUT TABLES AT CUTTING AGES AND USER SPECIFIED AGES (UP TO 76)
         5=OUTPUT TABLES EVERY YEAR
    NUMBER OF USER SPECIFIED AGES (0=NONE) 2,0,0
DO YOU WANT ECONOMICS TABLES FOR THIS RUN? Y
INDICATE DFSIM UNITS (CV4,CV6,IV6,SV6) CV4
ARE YOU USING A TABLE OF PONDVL PRICES? Y
ENTER # OF DBH VALUES
NO MORE THAN 8 DBH VALUES ARE ALLOWED 2
ENTER DBH VALUES (XX.X)
         6.,24.
ENTER PONDVL VALUES (XXXX.)
         860.,1490.
ARE YOU USING A TABLE OF LOGGING COSTS?
NOTE: THE TABLE FILE MUST BE PREDEFINED AS LOGICAL UNIT 13 BEFORE EXECUTING
SIMIN2. Y
ARE YOU USING A SEPARATE TABLE FOR FINAL HARVEST LOGGING COST VALUES? N
THE INTERMEDIATE HARVEST TABLE WILL ALSO BE USED
FOR FINAL HARVEST LOGGING COSTS

ENTER A 5-CHAR NAME OF INTERMEDIATE HARVEST TABLE TAB01
ENTER # OF DBH VALUES, # OF VOLUMES 10,6

DO YOU WANT TO INCLUDE SALVAGE OF MORTALITY ? Y
ENTER THE FOLLOWING PER ACRE COSTS:
    REGEN COST PER ACRE (XXXX.),
    PRECOM THIN COST PER ACRE (XXXX.),
    FIRST HARVEST ROAD COST PER ACRE (XXXX.),
    OTHER PER ACRE THIN COST (XXXX.),
    OTHER PER ACRE FINAL HARVEST COST (XXXX.).
         200,100,0,50,30
ENTER THE FOLLOWING VARIABLES:
    VOLUME ADJUSTMENT MULTIPLIER (X.XX),
    INTEREST RATE (XX.X),
    LOGGING COST MULTIPLIER (X.XX),
    OTHER PER M UNIT VOL THIN COST (XXXX.),
    OTHER PER M UNIT VOL FINAL HARVEST COST (XXXX.),
    HAULING COST PER M UNIT VOL (XXXX.).
         .90,4.,1.2,0,0,150
DO YOU WANT TO CHANGE PRICES OVER TIME? Y
ENTER POND VALUE PRICE TREND (XX.X) 1.5
DO YOU WANT TO CHANGE CULTURAL TREATMENT COSTS OVER TIME? Y
ENTER THE FOLLOWING RATES: (XX.X)
    REGEN COST TREND,
    PRECOM THIN COST TREND,
    FERT COST TREND.
         1,1,0

DO YOU WANT TO CHANGE HARVEST COSTS OVER TIME? Y
ENTER THE FOLLOWING RATES: (XX.X)
    LOGGING COST TREND,
    FIRST HARVEST ROAD COST TREND,
    OTHER PER ACRE HARVEST COST TREND,
    OTHER PER M UNIT VOL HARVEST COST TREND,
    HAULING COST TREND.
         0,0,1,0,0

DO YOU WISH TO SET UP ANOTHER RUN? N
```

Appendix 3
Input Form for DFSIM WITH ECONOMICS Short Control File

Title			
Site index Stand origin Age of PCT Stand option CT option Fertilization option			
Trees per acre			
Number of commercial thinnings			
Commercial thinning ages			
Commercial thinning options d/D ratios Stand basal areas Trees per acre			
d/D ratios			
Stand basal areas			
Trees per acre			
Earliest possible CT Minimum stand basal area Minimum quadratic mean DBH Minimum basal area			
Number of fertilizations			
Ages and rates			
Rotation age Height at rotation			
Output tables Number of user specified ages User specified ages			

nput Form for DFSIM WITH ECONOMICS hort Control File continued)

Units			
Table of pond values? Yes, number of DBH's DBH's Pond values No, coefficient A Coefficient B Coefficient C			
Table of logging costs? Separate final harvest table? Name intermediate table Number of DBH's, number of volumes Name final harvest table Number of DBH's, number of volumes			
Mortality salvage?			
Regeneration cost PCT cost First harvest road cost Other per acre thinning cost Other per acre final harvest cost			
Number of fertilization rate-cost pairs			
Rate-cost pairs			
Volume adjustment multiplier Interest rate Logging cost multiplier Other per unit volume thinning cost Other per unit volume final harvest cost Hauling cost			
Change pond values? Pond value trend			
Change cultural costs? Regeneration cost trend PCT cost trend Fertilization cost trend			
Change harvest costs? Logging cost trend Road cost trend Acre harvest cost trend Volume harvest cost trend Hauling cost trend			
RESULTS PNW1 PNW2 Soil expectation value Mean annual harvest			

Appendix 4

Example of DFSIM Control File

EXAMPLE DFSIM WITH ECONOMICS

```
125 0 11  300 0 0 0  4  0  0  0 1  80  0  0 0   0 0 0 0  0  0  0 0 0 2 0 1
  30   40   54   70    0    0    0    0    0                             2
 CV4  2 1   10  6  0  0 0.           0.           0.          1  .90
  40   200   100    0  120    0    50    0    30    0   150 1
 1.5  1.0  1.0  0.0  0.0  0.0  1.0  0.0  0.0
 6.0 24.0
 860. 1490.
      0.50  1.00  1.50  2.00  5.00 10.00
 6.0  723.  663.  630.  606.  546.  535.
 8.0  608.  549.  518.  497.  445.  435.
10.0  519.  462.  433.  413.  368.  359.
12.0  448.  392.  364.  345.  307.  298.
14.0  391.  337.  309.  291.  257.  249.
16.0  347.  293.  266.  249.  218.  210.
18.0  433.  332.  289.  264.  220.  208.
20.0  397.  296.  254.  230.  189.  177.
22.0  375.  274.  233.  209.  170.  158.
24.0  366.  266.  225.  201.  162.  151.
END
```

Appendix 5

Description of DFSIM WITH ECONOMICS Program Segments

SUBROUTINE ECON This is the controlling subroutine for the financial evaluation option. Calculates output results for each harvest. Calls LOGC, REVNOW, PONDV, and XMORT. Called by VOLCON.

SUBROUTINE EOUT Outputs the run parameter values for the financial evaluation option at the beginning of the 5.6-inch or 7.6-inch table and the financial summary tables at each harvest. Called by VOLCON.

FUNCTION LOGC Calculates logging cost per M units of volume from user table. Called by ECON.

FUNCTION REVNOW Calculates logging cost per M units of volume. It is valid for CV4 units only. Called by ECON.

FUNCTION PONDV Calculates pond value price from user table. Called by ECON.

SUBROUTINE XMORT Calculates salvage of mortality option. Called by ECON.

Fight, Roger D.; Chittester, Judith M.; Clendenen, Gary W. DFSIM WITH ECONOMICS: A financial analysis option for the DFSIM Douglas-fir simulator. Gen. Tech. Rep PNW-175. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 22 p.

A modified version of the DFSIM Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var *menziesii*) growth and yield simulator, DFSIM WITH ECONOMICS, now has an economics option that allows the user to estimate present net worth at the same time a silvicultural regime is simulated. If desired, the economics option will apply a volume adjustment multiplier in yields used in the analysis to reflect application of small-plot research results to average operating conditions or to account for genetics or other local conditions. It can also account for salvage of mortality. Prices can be entered as a table of values or as an equation that can vary with diameter. Logging costs can be entered as a table or can be generated internally for a short-span cable system. Logging costs can vary by diameter and volume harvested. Other harvest-related costs can be included on a per acre basis and also on a unit volume basis. Prices and costs can be trended using an annual percentage rate of change that is applied for a 50-year period

An interactive program, SIMIN2 WITH ECONOMICS, can be used to prepare the input data in the format required by the DFSIM WITH ECONOMICS program. Both programs are available from the Biometrics Group, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, P.O. Box 3890, Portland, Oregon 97208

Keywords: Simulation, financial analysis, DFSIM, Douglas-fir (coast).

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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Portland, Oregon 97208

General Technical Report
PNW-176 is available in
microfiche which is
located on third floor
in cabinets behind the
information desk.

United States
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Agriculture

Forest Service

Pacific Northwest
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PNW-177

December 1984

Forest Classification at High Latitudes as an Aid to Regeneration

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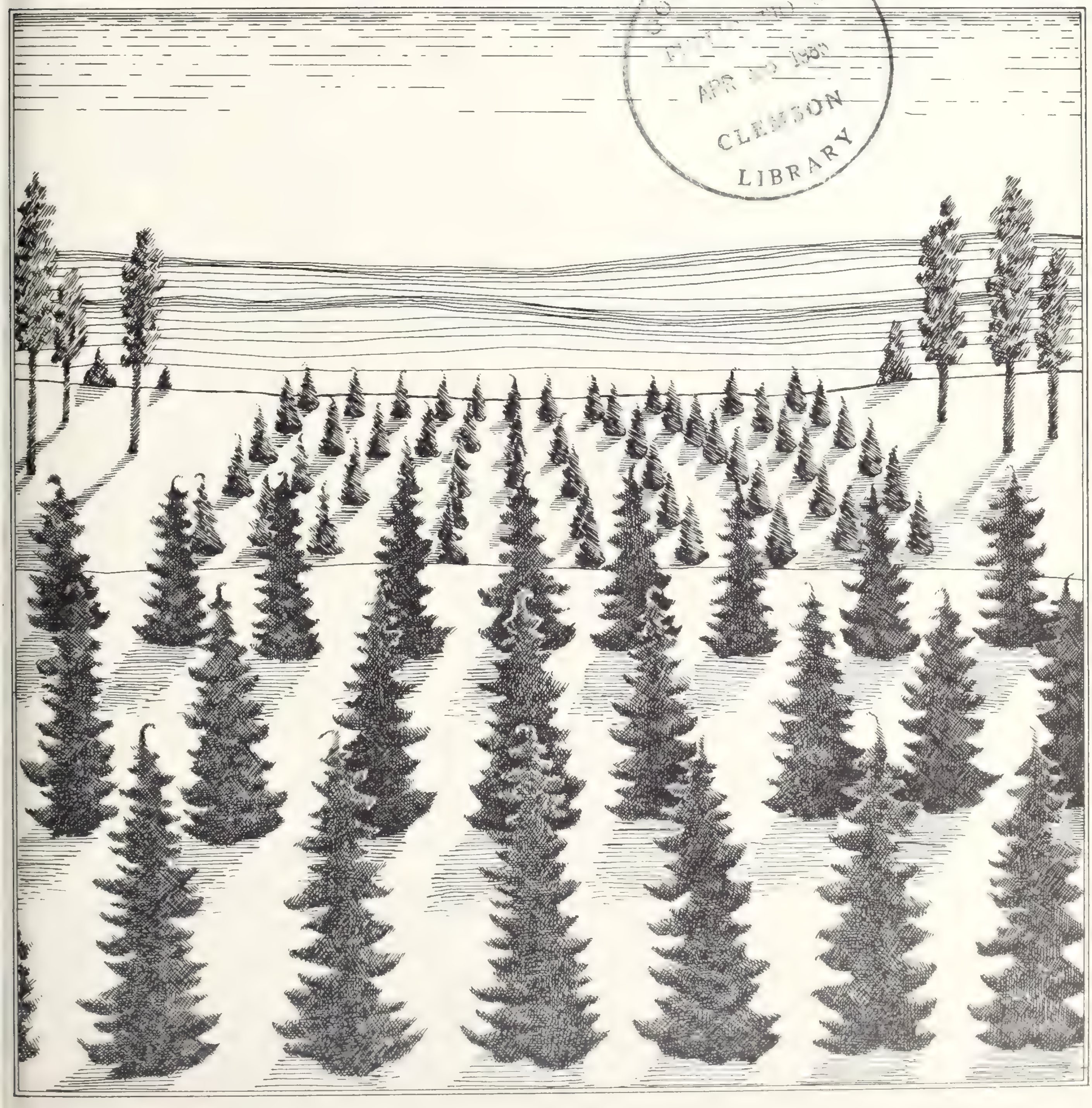

FOREST CLASSIFICATION AT HIGH LATITUDES AS AN AID TO REGENERATION

Edited by

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INTRODUCTION

Anthony F. Gasbarro

Early in 1979, the School of Agriculture and Land Resources Management of the University of Alaska-Fairbanks surveyed forest managers in a number of northern countries to identify topics of circumpolar interest in forest management. Responses most frequently centered on problems of forest regeneration. As a result, we initiated what was to be a series of international workshops to address the problem of obtaining adequate and economical forest regeneration at high latitudes. Our initial efforts were financed by a generous grant from the United States Department of Agriculture, U.S. Forest Service.

Since 1979, five workshops have been held, focusing on the problems of forest regeneration at high latitudes. These workshops and their respective topics were as follows:

Year	Workshop location	Topic
1979	Fairbanks, Alaska USA	General problems related to forest regeneration in the circumpolar north
1980	Umea, Sweden	Forest regeneration problems in Sweden
1981	Prince George, British Columbia, Canada	Forest regeneration problems in northwest Canada
1982	Hinton, Alberta, Canada	Management of lodgepole pine in the boreal forest
1983	Fairbanks, Alaska USA	Forest classification at high latitudes as an aid to forest regeneration

This report contains the papers given at the 1983 workshop. This workshop was sponsored by the School of Agriculture and Land Resources Management of the University of Alaska-Fairbanks. The principal organizers of the workshop were Mr. Anthony F. Gasbarro and Dr. Edward Packee. The objectives of the workshop were to review systems of site classification and to identify a system or systems for aiding forest regeneration and management at northern latitudes. Sincere appreciation is expressed to the authors of the papers in this publication.

The next workshop will be held in Edmundston, New Brunswick, Canada. It will address the yield advantages of artificial regeneration at high latitudes.

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AN ECOLOGICAL APPROACH TO FOREST MANAGEMENT

Edmond C. Packee

INTRODUCTION

Plants are social organisms and as such form communities. Man has recognized this from the earliest times with such concepts as forests, deserts, steppe, pine forest, oak forest, and meadow. Each grouping reflects relationships among the plants in the community. Man utilized these relationships to find food and clothing items.

Today, biological classification systematically arranges living things into groups based on natural relationships; table 1 provides an example from Porter (1959) of a hierarchial classification of the grass, *Poa pratensis*. An ecological classification systematically arranges communities of living things into groups; it may include only the living organisms or it may include both living organisms and the abiotic environment.

An ecological classification system for forest-management purposes requires both a biological base and an abiotic base that are independent of time. The biotic base recognizes that plants are social organisms that depend upon one another as well as compete with one another for the available resources of heat, water, light, and nutrients. The abiotic base provides information on the site's capacity to provide the basic resources. The site must be classified in such a way as to eliminate the vagaries of time; events such as fire, disease, insects, wind, and harvesting activities affect the successional status of a stand, and the classification must not reflect such seral stages. Within such a classification, each unit will be uniform with respect to soil conditions and successional communities. Hence, productivity, regeneration concerns, response to fertilizer treatments, and responses to other silvicultural practices will vary only within the limits of the unit described. Such units, regardless of classification level, can be referred to as biologically valid response units.

Table 1–The taxonomy of *Poa pratensis* (from Porter 1959)

- Kingdom–Plantae–the plant kingdom
  - Division–Embryophyta–the embryo plants
    - Subdivision–Phanaerogama–the seed plants
      - Branch–Angrospermae–seeds enclosed in an ovary
        - Class–Menocotyledoneae–the monocotyledons
          - Subclass–Glumiflorae–those with chaffy flowers
            - Order–Poales–the grasses and sedges
              - Family–Poaceae–the grass family
                - Subfamily–Festucoideae–those resembling Festuca
                  - Tribe–Festuceae–the Fescue tribe
                    - Genus–*Poa*–the bluegrasses
                      - Section–*Pratenses*–those with rhizomes
                        - Species–*Poa pratensis*–Kentucky bluegrass

Classification has two aims:

1. Identification of different items or units
2. Subdivision of broadly similar groups into even finer and more-specific groups (Porter 1959).

Furthermore, the classification must provide the basis for an information-storage and -retrieval system that is convenient for use. The classification is an organized index to information stored elsewhere. Finally, a good classification is an effective communication aid; the classification units provide a mental image for the parties involved.

As both an operational forester and a forest scientist, I am looking for a uniform classification of the forest ecosystems of North America and the boreal forests of the world. Josef Kostler (1956), the German forester, wrote in 1949 in Waldbau:

> As the objective of further researches, a uniform classification and standardizing of the central (and northern) European forests should be sought. That goal is still a long way off; pure plant-sociological description of forest associations has lost itself in such a multitude of types that their use for practical silvicultural problems has been rendered too difficult, apart from the fact that no uniform methods are applied.

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Table 2--A classification hierarchy of ecosystems

- Biome
  - Biogeoclimatic region
    - Biotic province
      - Vegetation zone
        - Vegetation series
          - Habitat type
            - Habitat-type phase
              - Ecosystem type

Is the situation today, one-third of a century later, any different? In western North America we have two soil classifications: the Canadian and the U.S.; we use various definitions/ concepts for the association; we have numerous ecological classifications: the biogeoclimatic approach using the edatopic grid of Krajina (1965, 1969) in British Columbia (Klinka et al. 1979); the habitat-type approach of Daubenmire (1952, 1968) in Washington (Daubenmire 1970), Idaho (Daubenmire and Daubenmire 1968, Pfister et al. 1977), and Montana (Pfister et al. 1977); and the biophysical land classification of Canada (Lacate 1969) in the Yukon Territory (Oswald and Senyk 1977).

With this general introduction, I will now present a preliminary classification of forest ecosystems. It is not perfect. However, the units are actual entities which can be described and mapped. The units can be used as a communication tool among land managers as well as foresters. The classification recognizes the major role of climate at the highest levels (biome, biogeoclimatic region, and biotic province), the combined effect of climate and topoedaphic features at the middle levels (vegetation zone and vegetation series), and the microenvironment at the lowest levels (habitat type, habitat-type phase, and the ecosystem type). Where appropriate, examples of the use of the classification unit in forest management are provided. In actual use, the level of the classification system required depends on the intensity of management desired.

The concepts behind the classification and the various levels are not new. Most have been used in many places, but under a variety of names. A comparison of terms used elsewhere is necessary; unfortunately, space does not permit that comparison here.

I do not pretend that this scheme is the ultimate or that it is perfect. "A 'perfect' biogeographic classification of the terrestrial world is, of course, an unattainable ideal" (Pielou 1979). I do contend that it is practicable and usable for intensive forest-management planning and prescriptions and for the extrapolation of data from elsewhere. It has been tried operationally and worked! Table 2 presents the general classification scheme.

CLASSIFICATION HIERARCHY

Biome

The biome is the broadest level of the taxonomy. It is the sum of the plant and animal community existing in the same geographic region (Barbour et al. 1980). Usage generally implies that the biome is a broad (continental/intercontinental) biotic community characterized by a distinctive appearance which is a response to a unique but broad range of environmental variables, especially climate (Odum 1971, Daubenmire 1978).

Table 3--Terrestrial biomes

Tundra
Coniferous forest
Deciduous forest
Grassland
Savannah
Tropical rain forest
Chaparral
Desert
Freshwater

Table 3 lists the terrestrial biomes of the earth. Note that the boreal forests of the world are not a biome. They fall within the Coniferous Forest Biome. The hardwood forests, seral stages of boreal forests, are included within the Coniferous Forest Biome since they are time dependent and generally require disturbance for their presence.

The biomes can be mapped. In terms of intensive forestry, their usage is limited. However, in terms of ecological processes, they provide a system for identifying major differences. Factors controlling nutrient cycling in the Deciduous Forest Biome and the Grassland Biome vary considerably from the factors in the Coniferous Forest Biome. Hence, any extrapolation of data from one biome to another must be done with great care. The greatest use of the biome is for the development of general hypotheses and theories regarding ecosystem processes and functions.

Biogeoclimatic Region

The biogeoclimatic region recognizes the regional differences in the biome. The biogeoclimatic region is a major geographic area still characterized vegetationally by a general uniformity of physiognomy, but it nevertheless recognizes differences in species composition of the overstory dominants. The difference in species composition reflects gross environmental differences, especially climate. Boundaries can be adrupt or gradual.

Within the Coniferous Forest Biome on the North American continent, there are east-west gradients and elevational gradients. Rowe's (1972) forest regions are essentially synonymous with the biogeoclimatic region and illustrate the gradients within the Canadian portions of the Coniferous Forest Biome; these are listed in table 4 along with some of their biological, geographical, and climatic characteristics.

As with the biome, the biogeoclimatic region has extremely limited utility for site-specific management interpretations. Their greatest utility is in the development of hypotheses and theories regarding ecosystem processes and structure. By recognizing the biogeoclimatic region and its characteristics, one can begin to test the validity of transferring ecosystem information from one location to another within the biome.

Data in table 4 indicate that low ambient temperatures and permafrost are characteristic features of the Northern Boreal Forest Biogeoclimatic Region; it would be difficult to transfer ecosystem-process information from there to the Coast Forest Biogeoclimatic Region. Similarly, transfer of data from the Acadian Biogeoclimatic Region to the Northern Boreal Forest should be done with great care.

Biotic Province

The biotic province is a geographic subdivision of a biogeoclimatic region that is distinguished by a degree of flora/

Table 4--Coniferous forest biogeoclimatic regions of Canada and representative environmental characteristics (from Rowe 1972)

	Forest Region						
Characteristic	Acadian	Southern boreal forest	Northern boreal forest and barren	Subalpine	Montane	Columbia	Coast
Bio (Characteristic species)	*Picea rubens* *Picea glauca* *Picea mariana* *Abies balsamea*	*P. glauca* *P. mariana* *A. balsamea* *Larix laricina*	*P. mariana* *P. glauca* *L. laricina*	*Abies lasiocarpa* *Picea engelmannii* *P. glauca* *Tsuga mertensiana* *Abies amabilis*	*Pseudotsuga menziesii* *Pinus ponderosa* *Pinus contorta*	*Tsuga heterophylla* *Thuja plicata* *P. menziesii* *Larix accidentalis*	*T. heterophylla* *T. plicata* *A. amabilis* *P. menziesii* *Picea sitchensis*
Geo (Geographic area)	Maritimes	Mid-Canada from Atlantic Ocean to Alaska	Subarctic (taiga) from Atlantic Ocean to Alaska	Higher elevations Rocky Mountains/ Coast Mountains	Interior B.C./ Southwestern Alberta	Columbia River/ Fraser River drainages	Coastal B.C.
Climatic (Climate)							
Mean Annual Temperature	5 to 7°C	-6 to 6°C	-9 to 0°C	0 to 2°C	2 to 8°C	7 to 8°C	8 to 11°C
Mean May to September Temperature	13 to 16°C	9 to 15°C	6 to 12°C	9 to 11°C	11 to 17°C	16 to 17°C	12 to 17°C
Number of days above 42°	184 to 210	125 to 171	89 to 144	138 to 156	159 to 206	148 to 211	222 to 292
Mean annual precipitation	81 to 142 cm	25 to 135 cm	23 to 79 cm	53 to 145 cm	25 to 64 cm	74 to 109 cm	69 to 320 cm
Mean May-September precipitation	36 to 53 cm	13 to 50 cm	15 to 41 cm	20 to 38 cm	13 to 38 cm	23 to 30 cm	13 to 81 cm
Potential evapotranspiration	53 to 58 cm	41 to 56 cm	36 to 46 cm	43 to 48 cm	48 to 64 cm	61 cm	61 to 69 cm
Soil Temperature	Cool soils	Intermittent permafrost	Permafrost	Cold soils	Warm soils	Cool soils	Cool-warm soils

fauna uniqueness. Dice (1943) elaborates on the uniqueness of the flora/fauna; in his definition, a biotic province "covers a considerable and continuous geographic area and is characterized by the occurrence of one or more important ecological associations that differ, at least in proportional area covered, from associations of adjacent provinces." Association, as used here, is synonymous with climax plant community. The geologic history of the flora is clearly imprinted in vegetation patterns; groups of plant species appear to "have had somewhat parallel histories of migration in recent geologic time, owing to common limitations in the configuration of land masses and climatic pressures that have induced migrations within each land mass. This is a significant point, since similar migratory patterns are evidence of a degree of similarity in the ecologies of the species" (Daubenmire 1968). In summary, then, a biotic province consists of biotic communities which have had a similar recent geologic and climatic history, which currently form a distinctive geographic unit, and which exhibit strong evidence of taxonomic homogeneity.

Figure 1 is a map of the tentative biotic provinces of coastal British Columbia and adjacent Washington and Oregon. Table 5 is a distribution table of the tree species present in each of the tentative biotic provinces; no attempt has been made to place any importance values on the species. Table 6 provides Jaccard's coefficient of community similarity for the tree species in each biotic province; the larger the number, the more similar are the biotic provinces being compared. From table 6 it is apparent that, on the basis of tree species alone, the Glacier Peak and Queen Charlotte Islands are most dissimilar.

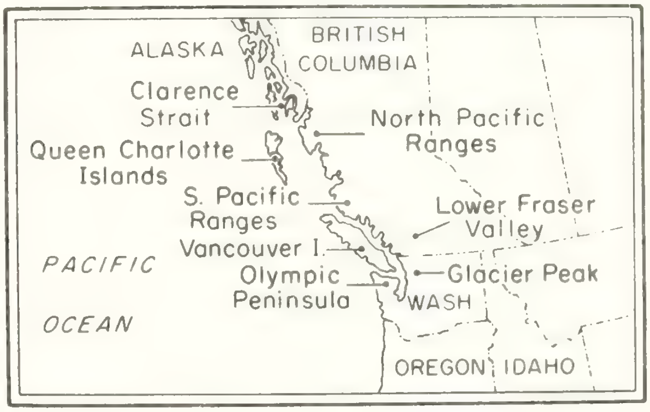


Figure 1.--Map of the biotic provinces of coastal British Columbia and adjacent Washington and Alaska.

On the other hand, Vancouver Island, South Pacific Ranges, Lower Fraser Valley, Olympic Peninsula, and Glacier Peak biotic provinces are quite similar and additional analyses using minor vegetation and/or fauna will be required to justify their continued separation.

The significance of the biotic provinces to the operational forester is often overlooked. Since there are geographical and biological differences between biotic provinces, there is a probability that environmental differences also occur. This suggests extra caution in transferring technology (e.g. planting-practice guidelines, stock type, survival/growth data) or

Table 5--Distribution of tree species by tentative biotic provinces in coastal British Columbia and adjacent Alaska and Washington

Conifers									
	Province*								
Species**	1	2	3	4	5	6	7	8	9
ABAM		+		+	+	+	+	+	+
ABGR					+	+	+	+	+
ABLA2	+	+		+	+	+	+	+	+
ABPR									+
CHNO	+	+	+	+	+	+	+	+	+
JUSC					+			+	
LALY									+
PIEN						+	+	+	+
PISI	+	+	+	+	+	+	+	+	+
PIAL				+		+	+		+
PICO	+	+	+	+	+	+	+	+	+
PIMO					+	+	+	+	+
PIPO									+
PSME				+	+	+	+	+	+
TABR		+	+	+	+	+	+	+	+
THPL		+	+	+	+	+	+	+	+
TSHE	+	+	+	+	+	+	+	+	+
TSME	+	+	+	+	+	+	+	+	+
	---	---	---	---	---	---	---	---	---
	6	9	7	11	13	14	14	14	17

Hardwoods									
	Province								
Species	1	2	3	4	5	6	7	8	9
ACCI					+	+	+	+	+
ACGL	+	+		+	+	+	+	+	+
ACMA				+	+	+	+	+	+
ALRU	+	+	+	+	+	+	+	+	+
ALSI	+	+	+	+	+	+	+	+	+
ALTE	+								
ARME					+	+	+	+	+
BEPA	+			+	+	+	+		+
CONU					+	+	+	+	+
POBA2	+								
POTR2	+			+	+	+	+		+
POTR	+	+			+	+	+	+	+
PREM				+	+	+	+	+	+
PRUI					+	+	+	+	+
PYFU	+	+	+	+	+	+	+	+	+
QUGA					+		+	+	+
	---	---	---	---	---	---	---	---	---
	9	5	3	8	14	13	14	12	14

*1 = Chatham Strait 3 = Queen Charlotte Islands 5 = Vancouver Island 7 = Lower Fraser Valley 9 = Glacier Peak
2 = Clarence Strait 4 = North Pacific Ranges 6 = South Pacific Ranges 8 = Olympic Peninsula

**Species coding follows that of Packee (1981), first two letters of genus and first two letters of species, e.g. ABAM = Abies amabilis

Table 6--Jaccard's coefficient of community similiarity (K = c/(a + b - c) for tentative biotic provinces of coastal British Columbia and adjacent Alaska and Washington, based on the presence of tree species

	Biotic Province*								
	1	2	3	4	5	6	7	8	9
1 (x)	1.00								
(y)	1.00								
(z)	1.00								
2 (x)	.61	1.00							
(y)	.67	1.00							
(z)	.56	1.00							
3 (x)	.47	.71	1.00						
(y)	.63	.78	1.00						
(z)	.33	.60	1.00						
4 (x)	.55	.74	.53	1.00					
(y)	.55	.82	.63	1.00					
(z)	.54	.62	.38	1.00					
5 (x)	.55	.52	.37	.64	1.00				
(y)	.46	.69	.54	.71	1.00				
(z)	.44	.36	.21	.57	1.00				
6 (x)	.45	.52	.37	.70	.86	1.00			
(y)	.43	.64	.50	.79	.80	1.00			
(z)	.44	.38	.23	.62	.93	1.00			
7 (x)	.43	.50	.36	.68	.90	.96	1.00		
(y)	.43	.64	.50	.79	.80	1.00	1.00		
(z)	.44	.36	.21	.57	1.00	.93	1.00		
8 (x)	.35	.54	.38	.61	.89	.83	.86	1.00	
(y)	.43	.64	.50	.67	.93	.87	.87	1.00	
(z)	.31	.42	.25	.47	.86	.79	.86	1.00	
9 (x)	.39	.45	.32	.61	.81	.87	.90	.78	1.00
(y)	.35	.53	.41	.65	.67	.82	.82	.72	1.00
(z)	.44	.36	.21	.57	1.00	.93	1.00	.86	1.00

x = conifers and hardwoods
y = conifers only
z = hardwoods only

* 1 = Chatham Strait
2 = Clarence Strait
3 = Queen Charlotte Islands
4 = North Pacific Ranges
5 = Vancouver Island
6 = South Pacific Ranges
7 = Lower Fraser Valley
8 = Olympic Peninsula
9 = Glacier Peak

biological material (e.g. seed) where the coefficient of community similarity is low, below 0.75. Using Jaccard's similarity coefficients from table 6, one can note an environmental gradient along the outer coast from the Olympic Peninsula to the Chatham Strait Biotic Province: 1.00, 0.89, 0.38, 0.54, 0.35. Factors that are associated with this gradient include: temperature, day-length, and snow. In addition, factors other than those associated with the gradient appear to be involved with the Queen Charlotte Islands; one major concern is their isolation which accounts for the lack of some species, especially the heavy seed *Abies amabilis* and *Abies lasiocarpa* which also suggests genetic population differences.

Vegetation Zone

A vegetation zone is a portion of the landscape ultimately occupied by a taxonomically closely related group of plant communities (Pfister et al. 1977). It is characterized by an individual or a distinct group of climax overstory dominants that reflects the macroclimate and are the most frequently occurring on the landscape. Since this group of overstory dominants is the most frequently occurring, the group can be considered as modal. Other overstory climax communities occur as minor components clustered around the modal climax community; these are, however, ignored in defining the vegetation zone since they reflect "abnormal" or extremes of soil, topography, or climate.

Daubenmire (1978) incorporates soil into his definition of the vegetation zone: "All the area in which zonal soils have the potentiality of supporting the same climatic climax plant association." Vegetation zones may occur as sequential belts on mountain slopes or on flat terrain. Figure 2 is a schematic representation of the vegetation zones found in the biotic provinces of south coastal British Columbia and adjacent northern Washington. The vegetation zone names are written in shorthand form: the first two letters of the genus and the first two letters of the species names; thus, ABAM-TSME

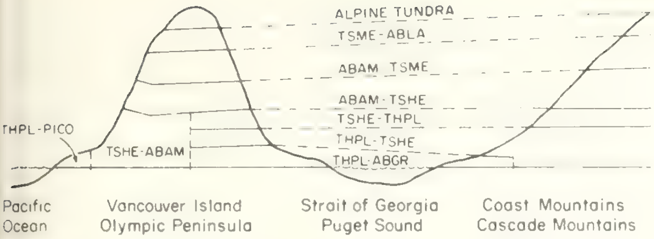


Figure 2.--Vegetation zones of south coastal British Columbia and adjacent Washington.

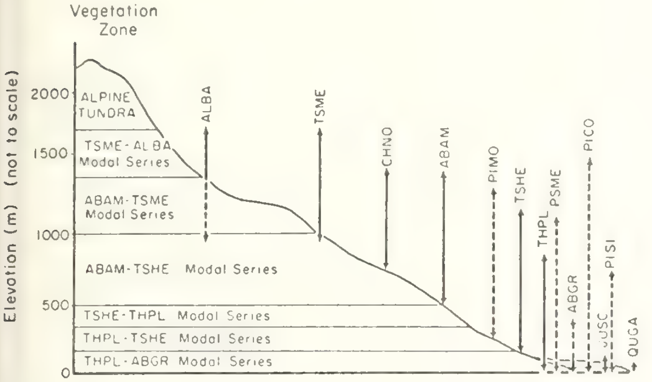


Figure 3.--Distribution of conifer trees in an area of the east coast of Vancouver Island, British Columbia. Arrows show the relative elevational range for each species; solid portion of range line indicates where a species is part of the potential climax and dashed portion where it is seral. Note that the modal vegetation identifies the vegetation zone.

stands for *Abies amabilis-Tsuga mertensiana*, and THPL-PICO stands for *Thuia plicate-Pinus contorta*.

In 1976, I published (Packee 1976) a demonstrated relationship among the vegetation zones in south coastal British Columbia based on potential soil-moisture deficits (both intensity and duration of a deficit) which reflect heat and water availability. Figure 3 is a schematic ordination of the vegetation zones along increasing moisture and decreasing temperature axes.

The vegetation zone is the broadest ecosystem unit which has site-specific implications for management. It is the first level of consideration for problem analyses, testing hypotheses, developing silvicultural guidelines, and planning. It also provides the entry into keys for determining the more specific ecosystem units (vegetation series, habitat type, and habitat-type phase).

Seed requirements should be determined for each species by vegetation zones. Generally, attempts are made to obtain a good representation (several provenances) of the site types within a vegetation zone. Sowing requests should attempt to match seed for a particular site to seed collected from a similar site of the same vegetation zone. Provenance studies should use vegetation zones as one ecological stratum for testing.

General guidelines for matching species to site should be based on vegetation-zone characteristics. For example, the two vegetation zones, ABAM-TSME and THPL-PICO, are considered to be largely unsuited for the management of *Pseudotsuga menziesii*. In the past it was planted in these vegetation zones; now that these zones can be readily identified, it is only planted on a very few specific sites.

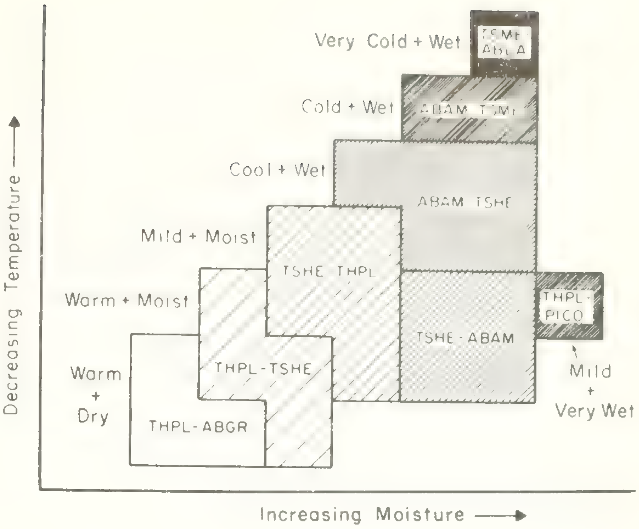


Figure 4.--Schematic ordination of vegetation zones of southern coastal British Columbia and adjacent Washington.

Vegetation zones can be used to identify potential seedling-survival hazards, time available for planting, and stock-acclimation requirements.

Vegetation Series

The vegetation series is a unit of the landscape potentially capable of supporting essentially the same overstory climax plant community. Owing to their upper-canopy position, such overstory species are strongly influenced by climate (Daubenmire 1968), however, strong topoedaphic factors also affect their occurrence. Through their effects on the understory environment of light, heat, moisture, and nutrients, to which other speices of the community must be adapted, the overstory dominants strongly determine the understory composition. Thus, the vegetation series is a hierarchial level intermediate between the macroenvironment (the vegetation zone) level and the microenvironment (the habitat type) level.

An understanding of the successional role of each overstory dominant species is essential to apply the vegetation-series concept. Figure 4 provides distributional as well as successional information about the species occurring on the east coast of Vancouver Island. Note that *Pinus contorta* (PICO) and *Pinus monticola* (PIMO), both common overstory species with a broad elevational range, are seral; therefore, since they are not climax, they do not participate in defining the vegetation series. Pfister et al. (1977) developed a key to the nine vegetation series found in Montana, which is reproduced as table 7. In both the Vancouver Island and Montana examples, relative shade tolerance is used to determine the successional status of the species.

The name of the vegetation series is based on the one or two most important climax species. In Montana, a single species was adequate; in coastal British Columbia, two species were necessary to identify the vegetation series.

The vegetation series provides the resource manager with basic information upon which to base gross management decisions for a specific site. It also provides the researcher with an ecological framework for designing studies.

In coastal British Columbia, some vegetation series automatically limit the level of intensive management, the species suitable for management, and the harvesting options. The

Table 7.--Key to vegetation series of western Montana and habitat types and habitat-type phases of the *Pinus flexilis* vegetation series (from Pfister et al. 1977).

Read These Instructions First!

1. Use this key for stands with a mature tree canopy that are not severely disturbed by grazing, logging, forest fire, etc. (If the stand is severely disturbed or in an early successional stage, the habitat type can best be determined by extrapolating from the nearest mature stand occupying a similar site.)

2. Accurately identify and record canopy coverages for all indicator species (appendix F).

3. Check plot data in the field to verify that the plot is representative of the stand as a whole. If not, take another plot.

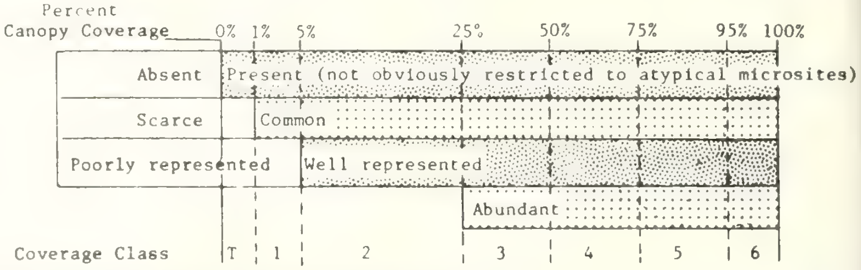
4. Identify the correct potential climax tree species in the SERIES key. (Generally, a tree species is considered reproducing successfully if 10 or more individuals per acre occupy or will occupy the site.)

5. Within the appropriate series, key to HABITAT TYPE by following the key literally. Determine PHASE by matching the stand conditions with the phase descriptions for the type. (The first phase description that fits the stand is the correct one.)

6. Use the definitions diagramed below for canopy coverage terms in the key. If you have difficulty deciding between types, refer to constancy and coverage data (appendix C-1) and the habitat type descriptions.

7. In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or duff accumulations, adjust the above definitions to the next lower coverage class (e.g., well represented >1%, common >0%).

8. Remember, the key is NOT the classification! Validate the determination made using the key by checking the written description.



KEY TO CLIMAX SERIES (Do Not Proceed Until You Have Read the Instructions!)

1. Habitats on steep slopes (30°) composed primarily of unstable fine rock; undergrowth sparse, poorly developed and quite variable. . . .	SCREE (p. 121)
1. Habitats on sites with some soil development and stability; undergrowth rather well developed and somewhat uniform.	2
2. Tsuga heterophylla present and reproducing successfully	TSUGA HETEROPHYLLA SERIES (item G)
2. Tsuga heterophylla not the indicated climax	3
3. Thuja plicata present and reproducing successfully.	THUJA PLICATA SERIES (item F)
3. Thuja plicata not the indicated climax.	4
4. Abies grandis present and reproducing more successfully than Abies lasiocarpa.	ABIES GRANDIS SERIES (item E)
4. Abies grandis not the indicated climax.	5
5. Abies lasiocarpa, Tsuga mertensiana, or Larix lyallii present and reproducing successfully, or Pinus albicaulis the dominant tree	ABIES LASIOCARPA SERIES (item I)
5. Not as above.	6
6. Picea present and reproducing successfully.	PICEA SERIES (item D)
6. Picea not the indicated climax.	7
7. Pinus flexilis a successfully reproducing dominant; often sharing that status with Pseudotsuga	PINUS FLEXILIS SERIES (item A)
7. Pinus flexilis absent or clearly seral.	8
8. Pseudotsuga menziesii present and reproducing successfully.	PSEUDOTSUGA MENZIESII SERIES (item C)
8. Pseudotsuga menziesii not the indicated climax.	9
9. Pure Pinus contorta stands, with little evidence as to potential climax.	PINUS CONTORTA SERIES (item H)
9. Pinus contorta absent; Pinus ponderosa the indicated climax	PINUS PONDEROSA SERIES (item B)

Key to *Pinus flexilis* Habitat Types

1. Festuca idahoensis well represented or F. scabrella common.	PINUS FLEXILIS/FESTUCA IDAHOENSIS h.t. (p. 25)
a. Festuca scabrella common.	FESTUCA SCABRELLA phase
b. F. scabrella scarce	FESTUCA IDAHOENSIS phase
1. F. idahoensis poorly represented and F. scabrella scarce.	2
2. Agropyron spicatum well represented	PINUS FLEXILIS/AGROPYRON SPICATUM h.t. (p. 24)
2. A. spicatum poorly represented; Juniperus communis (or J. horizontalis) well represented	PINUS FLEXILIS/JUNIPERUS COMMUNIS h.t. (p. 26)

Table 8.--Key to the habitat types and habitat-type phases of the *Pinus ponderosa* and *Pseudotsuga menziesii* vegetation series in western Montana (from Pfister et al. 1977).

Key to *Pinus ponderosa* Habitat Types

1. Prunus virginiana well represented, only in southeastern Montana	PINUS PONDEROSA/PRUNUS VIRGINIANA h.t. (p. 34)
a. Shepherdia canadensis well represented	SHEPHERDIA CANADENSIS phase
b. Shepherdia poorly represented	PRUNUS VIRGINIANA phase
1. P. virginiana poorly represented	2
2. Symphoricarpos albus well represented	PINUS PONDEROSA/SYMPHORICARPOS ALBUS h.t. (p. [illegible])
a. Berberis repens common	BERBERIS REPENS phase
b. Berberis scarce	SYMPHORICARPOS ALBUS phase
2. S. albus poorly represented	3
3. Purshia tridentata well represented	PINUS PONDEROSA/PURSHIA TRIDENTATA h.t. (p. [illegible])
a. Festuca idahoensis well represented or F. scabrella common	FESTUCA IDAHOENSIS phase
b. F. idahoensis poorly represented and F. scabrella scarce	AGROPYRON SPICATUM phase
3. Purshia poorly represented	4
4. Festuca idahoensis well represented or F. scabrella common	PINUS PONDEROSA/FESTUCA IDAHOENSIS h.t. (p. 31)
a. Festuca scabrella common	FESTUCA SCABRELLA phase
b. F. scabrella scarce	FESTUCA IDAHOENSIS phase
4. F. idahoensis poorly represented and F. scabrella scarce	5
5. Agropyron spicatum well represented	PINUS PONDEROSA/AGROPYRON SPICATUM h.t. (p. 30)
5. A. spicatum poorly represented; Andropogon spp. well represented	PINUS PONDEROSA/ANDROPOGON h.t. (p. 30)

Key to *Pseudotsuga menziesii* Habitat Types

1. Vaccinium caespitosum present	PSEUDOTSUGA MENZIESII/VACCINIUM CAESPITOSUM h.t.(p. 39)
1. V. caespitosum absent	2
2. Physocarpus malvaceus or Holodiscus discolor well represented	PSEUDOTSUGA MENZIESII/PHYSOCARPUS MALVACEUS h.t.(p. 41)
a. Calamagrostis rubescens and/or Carex geyeri are the dominant undergrowth	CALAMAGROSTIS RUBESCENS phase
b. Physocarpus and/or Holodiscus dominate the undergrowth.	PHYSOCARPUS MALVACEUS phase
2. Physocarpus and Holodiscus poorly represented	3
3. Linnaea borealis common	PSEUDOTSUGA MENZIESII/LINNAEA BOREALIS h.t.(p. 44)
a. Symphoricarpos albus well represented	SYMPHORICARPOS ALBUS phase
b. Vaccinium globulare well represented	VACCINIUM GLOBULARE phase
c. Not as above	CALAMAGROSTIS RUBESCENS phase
3. Linnaea scarce	4
4. Vaccinium globulare or Xerophyllum tenax well represented	PSEUDOTSUGA MENZIESII/VACCINIUM GLOBULARE h.t.(p. 45)
a. Arctostaphylos uva-ursi and Pinus ponderosa common	ARCTOSTAPHYLOS UVA-URSI phase
b. Xerophyllum common	XEROPHYLLUM TENAX phase
c. Not as above	VACCINIUM GLOBULARE phase
4. Vaccinium globulare and Xerophyllum tenax poorly represented	5
5. Symphoricarpos albus well represented	PSEUDOTSUGA MENZIESII/SYMPHORICARPOS ALBUS h.t.(p. 4[illegible])
a. Bunchgrasses well represented in old-growth stands	AGROPYRON SPICATUM phase
b. Calamagrostis rubescens well represented	CALAMAGROSTIS RUBESCENS phase
c. Not as above	SYMPHORICARPOS ALBUS phase
5. S. albus poorly represented	6
6. Calamagrostis rubescens well represented	PSEUDOTSUGA MENZIESII/CALAMAGROSTIS RUBESCENS h.t.(p. 47)
a. Bunchgrasses well represented in old-growth stands	AGROPYRON SPICATUM phase
b. Arctostaphylos uva-ursi common; sites capable of supporting Pinus ponderosa and not too dry for Pinus contorta (or Larix occidentalis)	ARCTOSTAPHYLOS UVA-URSI phase
c. Pinus ponderosa common	PINUS PONDEROSA phase
d. Not as above	CALAMAGROSTIS RUBESCENS phase
6. C. rubescens poorly represented	7
7. Carex geyeri well represented	PSEUDOTSUGA MENZIESII/CAREX GEYERI h.t.(p. 51)
7. C. geyeri poorly represented	8
8. Arctostaphylos uva-ursi well represented and Pinus ponderosa present	PSEUDOTSUGA MENZIESII/ARCTOSTAPHYLOS UVA-URSI h.t.(p. 52)
8. Arctostaphylos poorly represented or stands above elevational limits of Pinus ponderosa	9
9. Juniperus communis (or J. horizontalis) dominates the undergrowth	PSEUDOTSUGA MENZIESII/JUNIPERUS COMMUNIS h.t.(p. 53)
9. J. communis not the dominant undergrowth plant	10
10. Spiraea betulifolia well represented	PSEUDOTSUGA MENZIESII/SPIRAEA BETULIFOLIA h.t.(p. 52)
10. S. betulifolia poorly represented	11
11. Arnica cordifolia or Antennaria racemosa the dominant undergrowth	PSEUDOTSUGA MENZIESII/ARNICA CORDIFOLIA h.t.(p. 54)
11. A. cordifolia and A. racemosa not the dominant undergrowth	12
12. Festuca scabrella common	PSEUDOTSUGA MENZIESII/FESTUCA SCABRELLA h.t.(p. 38)
12. F. scabrella scarce	13
13. Symphoricarpos oreophilus well represented and Festuca idahoensis scarce	PSEUDOTSUGA MENZIESII/SYMPHORICARPOS OREOPHILUS h.t.(p. 55)
13. Not as above	14
14. Festuca idahoensis common; Pinus ponderosa scarce	PSEUDOTSUGA MENZIESII/FESTUCA IDAHOENSIS h.t.(p. 38)
14. F. idahoensis usually scarce; Agropyron spicatum well represented; Pinus ponderosa usually common	PSEUDOTSUGA MENZIESII/AGROPYRON SPICATUM h.t.(p. 37)

Table 9--Relative resource potential ratings for northern Idaho forest-habitat types[1] (from Pfister 1976)

	Resource potential ratings (1=very low to 10=very high)				
Habitat types[2]	Timber[3]	Big-game forage[4]	Domestic-livestock forage[5]	Water yield[6]	Esthetic recovery rate[7]
Pinus ponderosa/Stipa comata	2	1	6	1	1
Pinus ponderosa/Agropyron spicatum	2	2	10	1	3
Pinus ponderosa/Festuca idahoensis	3	3	10	1	3
Pinus ponderosa/Purshia tridentata	3	5	7	2	4
Pinus ponderosa/Symphoricarpos albus	5	4	8	2	5
Pinus ponderosa/Physocarpus malvaceus	6	7	7	3	7
Pseudotsuga menziesii/Symphoricarpos albus	6	5	7	3	6
Pseudotsuga menziesii/Physocarpus malvaceus	8	8	4	4	8
Pseudotsuga menziesii/Calamagrostis rubescens	6	4	5	4	3
Abies grandis/Pachistima myrsinites	9	10	3	5	10
Thuja plicata/Pachistima myrsinites	9	10	2	6	10
Thuja plicata/Athyrium filix-femina	7	6	1	?	9
Thuja plicata/Oplopanax horridum	7	6	1	?	9
Tsuga heterophylla/Pachistima myrsinites	10	10	2	7	10
Abies lasiocarpa/Pachistima myrsinites	7	10	2	8	9
Abies lasiocarpa/Xerophyllum tenax	4	4	1	6	4
Abies lasiocarpa/Menziesia ferruginea	6	6	1	10	8
Tsuga mertensiana/Xerophyllum tenax	3	4	1	10	8
Tsuga mertensiana/Menziesia ferruginea	5	6	1	10	8
Abies lasiocarpa/Vaccinium scoparium	4	4	3	8	2
Pinus albicaulis/Abies lasiocarpa	1	2	4	10	1

[1] Modified from Pfister, Robert; Schmautz, Jack; On, Danny, and Brown, Clarence. Management implications by habitat types. Training Manual, Mimeo, USDA For. Serv., North. Reg; 1971. 30 p.

[2] Habitat types: Daubenmire and Daubenmire (1968).

[3] Estimated relative yield capability based on available site index and yield data.

[4] Estimated relative amount of desirable forage for deer and elk produced in early successional stages.

[5] Estimated relative amount of desirable forage for cattle and sheep produced in later successional stages.

[6] Estimated relative off-site water-yield production, considering relative precipitation and relative evapotranspiration loss.

[7] Based on height of common seral species and rate of secondary succession following major vegetative disturbance and minor soil disturbance.

Alnus rubra vegetation series is suitable only for *Alnus rubra* or *Populus trichocarpa*, the value of the species for fiber is low, and environmental constraints and concerns strongly affect harvesting methods and accessibility. There is little justification for the investment of silvicultural resources on such marginal sites. Similarly, it is now well recognized that management for *Pseudotsuga menziesii* is questionable on all sites within the *Abies amabilis-Tsuga martensiana* vegetation series. Within the same vegetation series, alternatives to large clearcuts should be investigated since clearcutting commonly aggravates problems associated with prompt regeneration.

For the *Thuja plicata-Pinus contorta* vegetation series, the development engineer should recognize the impacts that harvesting and roadbuilding will have on the soil-moisture regime. Of major concern are paludification and blockage of the watercourses which will result in excess water on the site and reduced or lost productivity.

Habitat Type

The habitat type is "an aggregation of all land areas potentially capable of producing similar plant communities" (Pfister et al. 1977); "potentially" implies "at climax." Daubenmire (1978) defines habitat type as "a collective term for all parts of the land surface supporting or capable of supporting the same kind of climax plant association." The habitat type groups together as one unit various sites that support a particular climax plant community; although landform, soil, slope, aspect, and other site variables individually can be quite different, the sum of these variables results in essentially equivalent climax plant communities.

Because of the impact that the overstory community exerts on the understory environment, the understory plant community not only reflects topographic and edaphic conditions, but also biologically imposed conditions. One of the most obvious biological impacts of the overstory climax vegetation is its affect on the quantity and quality of light reaching the lower plant strata. The more dense the shade, the more shade tolerant must be the understory species. Yet light does not explain everything! The overstory canopy reduces the solar radiation reaching the forest floor; this reduces the amount of heat reaching the forest floor. The less the solar radiation, the cooler the soil and the longer the retention of snowpack. This favors the survival of the more cold-tolerant species over the more heat-demanding species.

The habitat type is described by the overstory climax plant community and the associated understory community. The vegetation series describes the overstory community; the understory community is described using a limited, but adequate, number of characteristic understory species. Tables 7 and 8 are keys to habitat types for three of the vegetation series in Montana as presented by Pfister et al. (1977). Note the emphasis on following instructions in spite of the apparent simplicity.

Habitat types are a primary management unit. They are reference points for evaluating the environmental setting and predicting response. They are intended for use by resource managers and scientists.

Habitat types have been used for many forest-managment activities. Table 9 provides an example from Pfister (1976) of

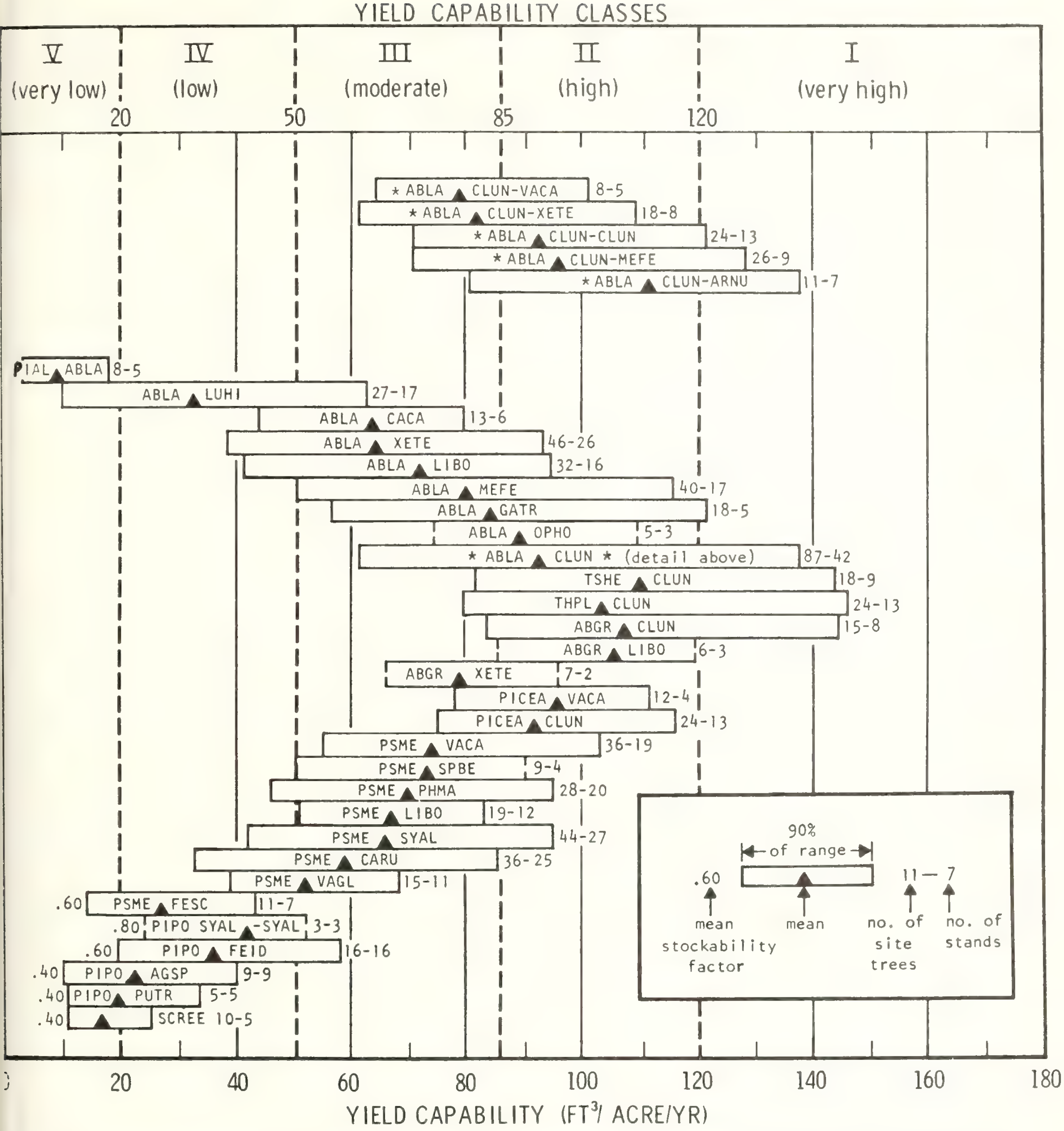


Figure 5.--Estimated yield capabilities of west-side Montana habitat types based on site-index data and stockability factors. (Kootenai, Flathead, Lolo, and Bitterroot National Forests) (from Pfister et al. 1977).

using habitat types to rate the resource potential of forest lands in northern Idaho. Figure 5 provides timber-yield capability classes for habitat types found in West-side Montana forests (Pfister et al. 1977). Habitat types are useful for identifying preferred and acceptable species for management. Obviously, it is risky to manage for a species on sites where it does not occur naturally or is under stress. Equally important is the identification of the most-appropriate species in terms of yield, value, and cost of establishment and maintenance. The habitat type permits prediction of plant succession following disturbance. This should permit early identification of brush or grass problems and the selection of appropriate site-preparation methods and necessary stand-tending practices. The habitat type has been used to identify logging-equipment limitations, setting, boundaries, and windthrow risk.

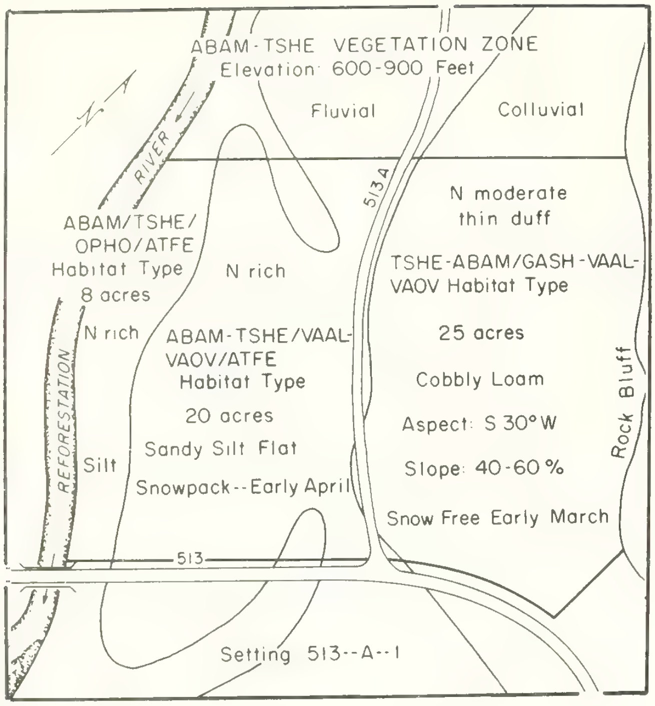
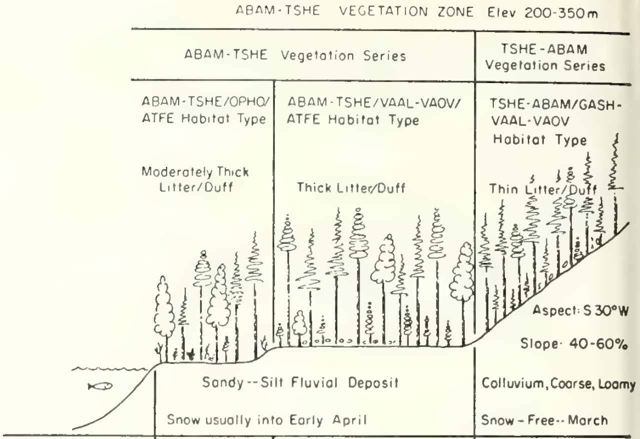


Figure 6.--Map of habitat types for a logging setting on Vancouver Island.



Species Preference	THPL	ABAM-TSHE	PSME
Regeneration Method	Plant 750/acre	Plant ABAM 450/acre TSHE Seeds naturally	Plant 450/acre
Site Preparation:	Burn, Brush, Alder seed-tree control	Burn, Brush, Alder seed-tree control	Log clean, No fire
Competition:	Salmonberry Alder	Salmonberry & Huckleberry Alder	
Nutrition (N):	Adequate	Urea with S	Urea at 200 lb N/acre
Logging Constraints	No Skidders Stream Care	No Skidders	

Figure 7.--Cross-sectional sketch of logging setting of Figure 6 with prescriptions.

Figure 6 is a map of an actual logging setting on Vancouver Island. It is in a cold-air drainage corridor involving two major land-form types: fluvial and colluvial. Figure 7 is a schematic cross-sectional view of the setting. Below the sketch are the prescriptions for the three habitat types within the setting. Note the immediate regeneration-related concerns: species preference, regeneration method, desired number of stems per acre, and site-preparation requirements.

In conclusion, an ecological classification based on valid biological response is an important forest-management tool. At this time classification to the habitat-type level appears to be more than adequate in North America. Management at this level is now only beginning to be tried. Classificaton to more—specific units, the habitat-type phase, and ecosystem type (the latter incorporating specific soils information) is not warranted until operationally deemed necessary. Hence these two levels have not been discussed in this presentation. At a later date, as forest management becomes more intense, they might have an essential role.

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DEVELOPMENT AND USE OF AN ECOLOGICAL CLASSIFICATION SYSTEM

Robert D. Pfister

INTRODUCTION

Several classification systems have been applied to North American forests during the past century. Different purposes and scales have lead to development of forest-cover types, plant-community types, plant associations, potential natural-vegetation types, forest region, biogeocoenoses, habitat types, site types, and others. The purpose of this paper is to review the steps involved in developing an ecological site classification; from planning, to development, to application. Forest habitat-type classification efforts in Montana, (Pfister et al. 1977, Pfister and Arno 1980), will be used as a specific example of the general approach.

USER NEEDS

If the primary justification for developing a classification system is to meet forest-management needs, then these needs must be a primary consideration in designing the approach and the ultimate product. A set of binary questions may help focus on these needs:

1. Do you want a vegetation classification or a site classification?
2. Do you want a user-friendly taxonomy or do you want a completed map?
3. Do you want existing vegetation types or potential (climax) vegetation types?
4. Will the system be used for field identification of types on plots and stands (large scale) or for office planning of larger areas (small scale)?

For example, Montana habitat types were developed 1) as a site-classification system, 2) with a user-friendly taxonomy, 3) based on the concept of potential (climax) vegetation types (by sampling only later successional stages), and 4) primarily as a tool for typal identification of plots and individual stands. The taxonomy then served as a foundation for operation mapping and use in area planning.

ECOLOGICAL PRINCIPLES

An ecological classification will only be as sound as the principles upon which it is based. The following principles are some of the important considerations in developing any ecological classification system. They are mentioned only briefly here but are elaborated on elsewhere (Daubenmire 1968, Mueller-Dombois and Ellenberg 1974).

1. The ecosystem (biogeocoenosis) concept provides a logical framework for classification concepts.

The ecosystem framework can be used to illustrate the individual structural components, their relationships, and how each component is related to a specific classification approach. In our forest habitat-type classifications, the phytocoenosis (plant-community type) is used as an integrated expression of the physical environment.

2. Different site-factor combinations provide "equivalent environments."

Two environments (sites) can be equivalent in the combined conditions for plant growth even though individual site factors may be quite different. For example, a sandy soil with 20 inches of precipitation could produce a plant community similar to that found on a loamy soil with 10 inches of precipitation. This is a logical extension of the ecological principle of "factor interaction."

3. Plant communities vary in time and space.

Most introductions to plant ecology illustrate how time and environment interact to produce different plant communities. The concept is simple but the interactions are complex as illustrated by the diversity of any landscape — a mosaic of time and space relationships. The focus of the classification exercise is to define classification boundaries in space and time. (At this point, continuum advocates are quick to point out the problems of continuous variation; ecologists with a classification goal will proceed to utilize the boundaries evident on the landscape and develop a rational approach to

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define operational boundaries for subdividing areas of apparent continuous variation.)

4. Climax (stable) communities are the best indicators of environment (for vegetation).

With time and space varying together, one must be held constant to examine variation in the other. Successional change is relatively slow as one approaches climax (self-perpetuating) conditions. Therefore, it is logical to begin a study of environmental variation with the study of climax vegetation.

5. The climax concept must be defined for the study area.

Daubenmire (1952) searched diligently for climax and near-climax stands. In Montana (Pfister and Arno 1980) we were able to relax stand-selection criteria to include late-seral stands, thereby greatly increasing efficiency. Therefore, our data base provides a less-precise documentation of potential climax, but still meets the criteria of a relatively stable stage of development along the successional (time) gradient. The undergrowth vegetation stabilizes quite rapidly under the forest canopy, and the successional direction of the tree component can be predicted quite confidently from a stand table and current knowledge of the autecology of the tree species. Thus, the operational definition of climax for classification purposes in Montana was about 300 to 500 years.

6. The plant association (climax) provides the basis for the site classification.

Daubenmire built upon the foundation of the definition of plant association "agreed" upon at the 1910 International Botanical Congress — a kind of "plant community of definite composition, presenting a uniform physiognomy and growing on uniform habitat conditions." Recognizing that this definition does not mention variation due to succession (time), Daubenmire used "association" only in reference to climax community types. (Many ecologists have not been that restrictive in their usage of the term "association" — hence, confusion.) From this definition, we see the logical derivation of the term "habitat type" from the 1910 definition. If the 1910 Congress had substituted the word "site" for "habitat," the logical term should have been "site type" as used by scientists with a stronger forestry background vs. a plant-ecology background. To avoid some of this confusion, we (Pfister et al. 1977) define "association" as "climax plant community type" and point out that habitat types are site-typing taxonomy based on classification of potential climax communities.

OBJECTIVES

Objectives must be clearly specified for an ecological classification study because of the numerous possible directions that are possible. For instance, should one pursue a natural classification or a technical one? Is the immediate objective a taxonomic system or a mapping system? Should the classification address all existing vegetation types or focus on potential climax? Who will use the classification and for what purposes? Fundamental differences among numerous possible approaches are discussed by Bailey et al. (1978).

When we started the Montana efforts in 1970, we had the benefit of experience in using the Daubenmires' (1952, 1968) classification for several years. Primary funding was provided to produce a similar, compatible system for Montana. Therefore our objectives were to:

1. Develop a habitat type classification for the forests of Montana (a taxonomy of "site types" called habitat types for conformity with previous terminology in the Northern Rocky Mountains).
2. Describe the vegetation of later successional stages of the habitat types.
3. Describe the physical environments (site factors) of the habitat types.
4. Provide management implications for the habitat types.

In effect, this called for a natural, taxonomic classification based on potential climax vegetation for use by field foresters in the process of site identification, habitat-type mapping, and application of available management implications.

DATA BASE

The data base (along with principles) provides the foundation for developing the classification. Details are provided by Pfister and Arno (1980). Briefly, our goal was to objectively and efficiently sample the oldest available successional communities from a full range of environments. Sampling theory was predicated on a philosophy discussed in Mueller-Dombois and Ellenberg (1974) as "subjective without bias." This translates to first recognizing homogeneous stands in the field (stratification) and sampling them to avoid any bias related to preconceived notions about the outcome of the classification system. Replication was achieved by sampling transects in different geographic areas, with different crews, prior to grouping stands into classes. Sample size for each type is therefore not known until the classification is completed. Plot size was 375 m^2 (ca. 1/10 acre). Stand data included tree species, diameter, age, and structure. Coverage data for all undergrowth species was collected. Physical site variables and a minimal soils description were recorded. Data and observations pertinent to management implications were also recorded. The plant-community data are essential to developing the taxonomy. Site data are useful in testing the classification and describing the physical environment. Other data collection is somewhat flexible depending on intended uses and feasibility.

SELECTING APPROPRIATE ANALYSIS TECHNIQUES

With the advent of computers and "mathematical ecology," there are numerous ways to analyze the data, but the final classification still must reflect the judgement of the ecologist. First, in selection of analytical tools; second, in weighting the data; and third, in fine-tuning the classification to reflect the combination of all important variables. We used the following techniques in building the classification (Pfister and Arno 1977):

1. Initial subjective groupings based on classification from adjoining areas and field observations.
2. Successive synthesis tables (computer generated) to display all species by all stands at each approximation of the classification.
3. Indirect ordinations to display and evaluate species distributions.
4. Indirect ordinations to display and evaluate type distributions.
5. Collective judgement of team members.
6. Scientific method of "successive approximations."

DEVELOPING, TESTING, AND REFINING TAXONOMY

Using the above techniques, the classification progressed through at least four approximations based on analysis of vegetation data. At that point, the physical-site data were analyzed for each type to examine relationships and anomalies. The "fifth approximation" became the "preliminary" classification and was released to field foresters for field testing and feedback to the classification team. The essential components of the preliminary classification include: 1) a list of types, 2) descriptions of vegetation types, 3) descriptions of physical environments, 4) a key for identification, and 5) management implications. Following this testing, and with inclusion of additional data from problem areas, the review draft of the "final" classification was prepared for operational use and for peer review as a formal publication. Although labelled "final" publication, the "successive" approximation philosophy suggests future revision may be appropriate. However, a point of diminishing return is reached rapidly when the classifier becomes trapped in a continuous revision cycle.

DESCRIPTION OF VEGETATION TYPES

The description of the vegetation is readily accomplished from the synthesis tables used in the analyses. An average or modal description and appendix table provide the user with a summary of species occurrence and quantities sampled in the type. Successional interpretations are also provided. Thus, one obtains a vegetation classification of later successional stages as a spin-off from a site-classification objective.

DESCRIPTION OF PHYSICAL ENVIRONMENT

This description includes elevations, aspects, slope configurations, geographic area, and soils information from the original data base, summarized for each type. As other inventories are conducted using the defined types, additional data become available for an expanded site description.

DEVELOP A KEY FOR IDENTIFICATION

Have you ever tried to use a classification system (list of types) that doesn't have a key? The key is a crucial element for obtaining use of the taxonomy by a wide audience of potential users. Developing an efficient, accurate key is a demanding task, but well worth the effort to prevent user frustration and numerous questions. It is usually defined for application throughout all but the very earliest stage of secondary succession.

PROVIDING MANAGEMENT IMPLICATIONS

A site taxonomy without management implications will gather dust on the shelf of a manager's library. It is not enough to be able merely to put the "proper" name on a unit of land. In Montana, we collected enough site-index data and multiresource observations to provide some direct-management implications as part of the taxonomy package. These have been a key to wide acceptance and provide a foundation for continual improvement of management implications based on additional research and management experience tied to the taxonomic classification.

TRAIN USERS OF TAXONOMY

The normal lag time for acceptance and use of new knowledge is 10 to 20 years. Without training, a new system is often misapplied and rejected for the wrong reasons. Formal training sessions (annual week-long sessions of 40-60 foresters and biologists) have been conducted since the advent of the first preliminary classification (1971-western Montana). The need continues as foresters transfer and new foresters are hired. People completing the training are usually qualified to use the system appropriately for their own management activities, to map habitat types, and to train field crews in the basics of habitat-type identification.

We soon learned that a major stumbling block was the inability of foresters to identify undergrowth species. The major instructional objectives of current training sessions are to provide:

1. Ability to identify all indicator species.
2. Understanding of ecological principles pertinent to habitat types.
3. Ability to identify habitat types accurately through proper use of the key, descriptions, and appendix information.
4. Introduction to habitat-type mapping methodology.
5. Ability to make appropriate use of direct management implications.
6. Introduction to use of the classification document for deriving indirect management implications.

Widespread acceptance, enthusiastic use, and continued demand for training new people demonstrate the utility of the classification for forest multiple-use management. Few other mangement tools are as readily transferable to the potential users.

CONCLUSION

I have used the Montana examples to illustrate development and use of a site-classification system called "habitat types." Credit for the concept goes to Daubenmire for his pioneering work in northern Idaho and adjacent Washington. He demonstrated the approach and defended the concepts, although it took forestry organizations 18 years to get serious about using the system.

Development of a system for a new area requires recognition of the major work involved. Full-time ecologists are essential to direct the field and lab activities and to wrestle with the anomalies of ecological theory. Computer-assisted analyses provide good efficiency for developing the taxonomy. Management implications — present and future — provide the payoff for land-manager involvement.

Training is the key to ensuring use of the classification by managers. Developers of the classification must commit the time and energy to transfering their knowledge. The system is well adapted to user application, thereby freeing the ecologist for working on further management implications and knowledge of succession in relation to management treatments.

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THE IMPORTANCE OF PREDICTIVE MODELS OF FOREST SUCCESSION TO SILVICULTURE MANAGEMENT

Dale A. Draper and Evelyn H. Hamilton

INTRODUCTION

The Prince George Forest Region (P.G.F.R.), nearly 30 million hectares in total area, is one of six administrative units within the British Columbia Ministry of Forests. The region is situated in the northeast corner of the province, bounded by Alberta and the Yukon and Northwest Territories to the east and north, and by other administrative units within the province to the south and west (fig. 1).

Main physiographic features in the region are the Alberta Plateau to the east of the Rocky Mountains and the northern portion of the Interior Plateau west of the same range. The area as a whole is characterized by a continental climate with cold to very cold winters and short, cool to relatively warm summers.

The forests in the northern part of the P.G.F.R. include the Boreal White and Black Spruce (BWBS) Zone, which extends from the Alberta Plateau in the northeast corner of the province into valley bottoms at elevations below about 1000 m. The subalpine Spruce-Willow-Birch (SWB) Zone occurs at elevations above the BWBS and below the Alpine Tundra Zone north of about 57° N latitude. The Sub-Boreal Spruce (SBS) Zone is found between 500 and 1300 m elevation on the Nechako and Fraser Plateaus and in the Fraser Basin in the central part of the region. The Engelmann Spruce-Sub-Alpine Fir (ESSF) Zone occurs at elevations above the SBS in the mountainous regions south of about 57° N latitude. Finally, the Interior-Cedar-Hemlock (ICH) Zone extends up the Rocky Mountain Trench into the southern part of the region (Pojar 1983).

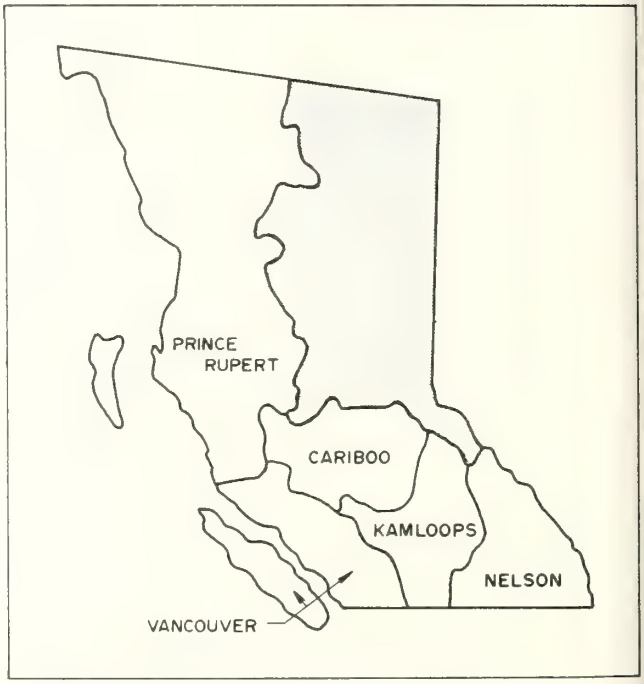

Figure 1--Prince George Forest Region.

The 17 million hectares of productive forest land in the region are divided approximately equally into mature forest (7.8 million ha) and immature forest (8.2 million ha); the remainder (1.3 million ha) is classed as noncommercial brush species, nonsatisfactorally stocked or other.

EXISTING ECOLOGICAL CLASSIFICATION

The Research Branch of the Ministry of Forests has developed an ecological classification of lands under the ministry's

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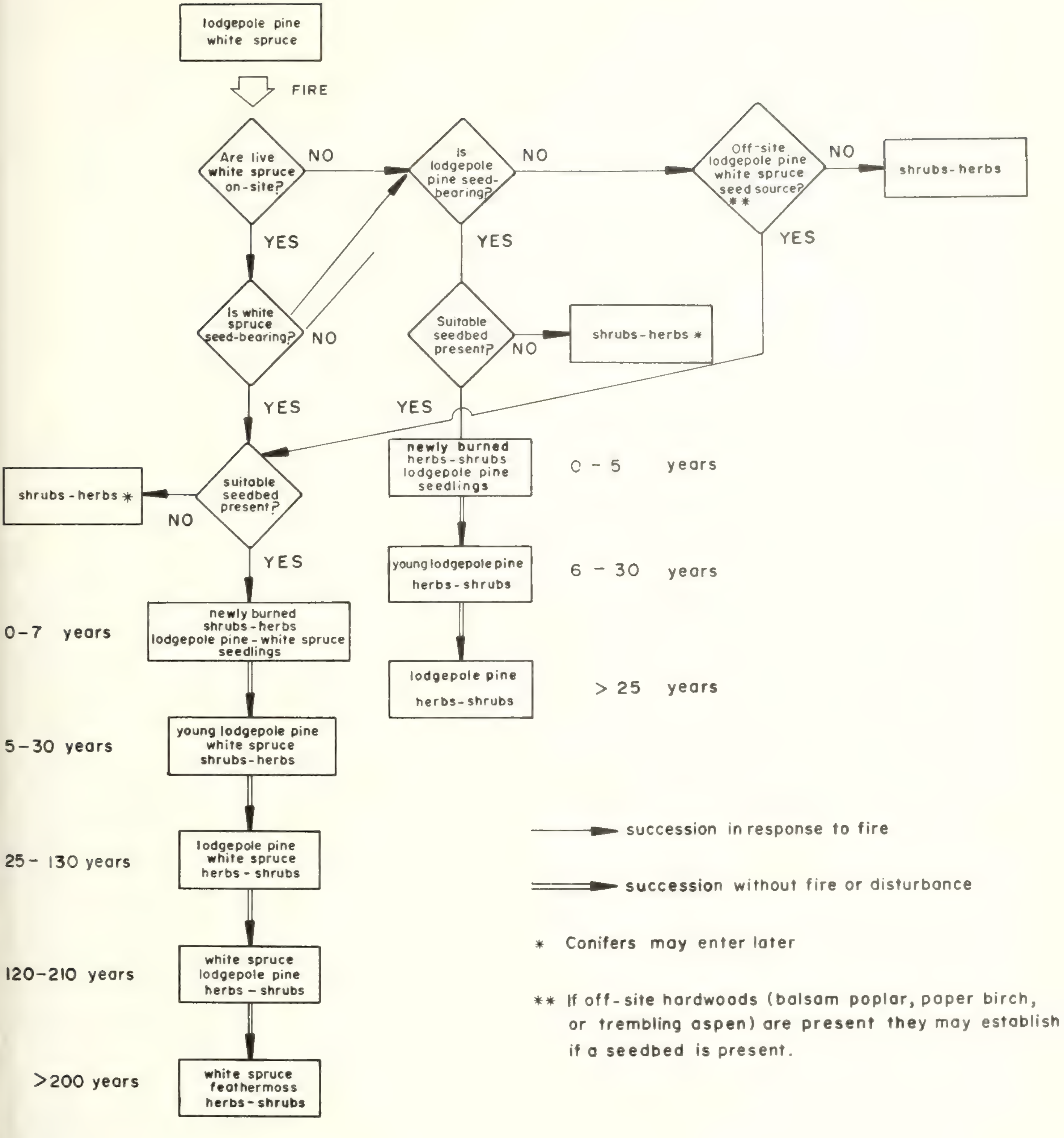
lodgepole pine
white spruce
FIRE
Are live white spruce on-site?
NO
YES
Is white spruce seed-bearing?
NO
YES
suitable seedbed present?
NO
shrubs - herbs *
YES
0-7 years
newly burned shrubs - herbs lodgepole pine - white spruce seedlings
5-30 years
young lodgepole pine white spruce shrubs - herbs
25- 130 years
lodgepole pine white spruce herbs - shrubs
120-210 years
white spruce lodgepole pine herbs – shrubs
>200 years
white spruce feathermoss herbs - shrubs
Is lodgepole pine seed-bearing?
NO
YES
Suitable seedbed present?
NO
shrubs - herbs *
YES
newly burned herbs - shrubs lodgepole pine seedlings
0 – 5 years
young lodgepole pine herbs - shrubs
6 – 30 years
lodgepole pine herbs - shrubs
> 25 years
Off-site lodgepole pine white spruce seed source? **
NO
shrubs - herbs
YES
succession in response to fire
succession without fire or disturbance
* Conifers may enter later
** If off-site hardwoods (balsam poplar, paper birch, or trembling aspen) are present they may establish if a seedbed is present.

Figure 2.–Successional pathways in a Boreal White and Black Spruce Biogeoclimatic Zone and Northern White and Black Spruce Subzone (from Parminter, 1983).

Table 1. Successional classification of a white spruce (*Picea glauca* [Moench] Voss) ecosystem association

Condition or Treatment	Pioneer Seral	Young Seral	Maturing Seral	Over mature Seral	Climax
Natural Succession	PS1[1]→PS2[2] →	YS1[3] →	MS1[4] →	OMS1[5] →	C[6]
Severe Fire	PS2 →	YS1 →	MS1 →	OMS1 →	C
Logging	PS1 →	YS1 →	MS1 →	OMS1 →	C
Light-Medium Fire		YS1 →	MS1 →	OMS1 →	C
Approximate Stand Ages (Years)	0-15	15-60	60-140	140-200	250+

[1] Pioneer shrub and herb stage occurring immediately after disturbance.

[2] Pioneer shrub and herb stage including *Populus tremuloides* Michx., *P. balsamifera* L., *Salix* spp., *Rosa acicularis* Lindl., *Epilobium angustifolium* L., and *Aster conspicuous* Lindl.

[3] Young seral stand dominated by *Populus tremuloides, P. balsamifera* with sparse *Picea glauca*, and including *Salix* spp., *Calamogrostis canadensis* (Michx.) Nutt., and *Rosa acicularis* Lindl.

[4] Maturing seral stand dominated by *Populus tremuloides*, with *Picea glauca* regeneration, *Populus balsamifera, Betula papyrifera* Marsh. and *Cornus sericea* L. also present.

[5] Overmature seral stand with *Populus tremuloides, P. balsamifera*, and *Picea glauca*. Persistent seral species remain. Snags and deadfalls are abundant. *Picea glauca* is regenerating.

[6] Climatic climax stand of *Picea glauca*.

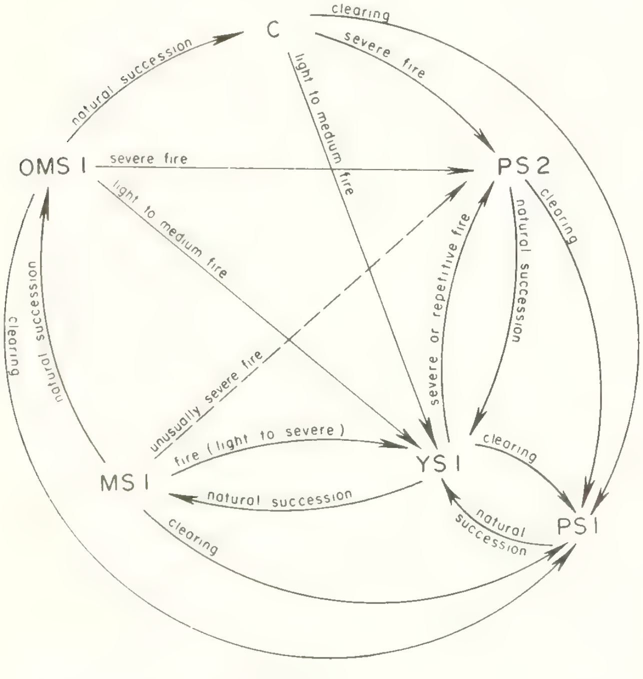

Figure 3.–Successional Pathways in a White Spruce Ecosystem Association (adapted from Harcombe et al. 1980).

jurisdiction to provide an information system to assist in the improvement of forest and range management. A modification of the Biogeoclimatic system developed by V. J. Krajina and his associates (Krajina 1969, 1972), is used as a basis for this classification (Pojar 1983).

Classifications are made at two levels: first, at the biogeoclimatic level where the land base is divided into regions which have homogeneous climatic conditions; and second, at the ecosystem level where units similar in terms of their vegetation, soil, and function are identified.

The classification of ecosystems is based upon sampling of climax or near-climax forests. Once classification is completed the ecosystems will be examined in greater detail to evaluate ecological change over time and under differing silvicultural management. Methods for the identification and classification of stages in the successional process are under development.

STATUS OF SUCCESSIONAL RESEARCH

Although there are many studies of forest succession in North America, few are specific to northern British Columbia.

Generalized postwildfire successional sequences in the boreal forests of western Canada and Alaska can be found in Lutz (1956), Kershaw et al. (1975), Viereck (1970), Maikawa and Kershaw (1976), and Foote (1983). Summaries of existing knowledge of boreal succession are provided by Kelsall et al. (1977), Johnson and Rowe (1977), Larson (1980), and Viereck and Schandelmeier (1980).

Forest successional studies in northern British Columbia include Parminter (1983 a, b), who examined sequences arising after wild-fire in the Fort Nelson and Cassiar Timber Supply Area. Here successional pathways were explained in terms of presence or absence of a seed source and suitable seed bed (fig. 2). Harcombe (1978) described the seral and climax plant communities of the Northeast Coal Area, between Prince George and Fort St. John, and briefly outlined seral pathways on different landforms. Vegetation succession following logging and fires of various frequency and intensity near Fort St. John are descried in more detail by Harcombe et al. (1980). Figure 3 is adapted from this source and gives an example of successional pathways identified in a white spruce ecosystem association. Table 1 provides the description and definition of terms used in this figure.

An initial classification of ecosystems in the BWBS zone in the P.G.F.R. has been completed and ecosystem-specific silvicultural prescriptions, reflecting the current understanding of seral processes, are under development (L. Jang, pers. comm., March, 1983).

Successional sequences in other forest zones in the P.G.F.R. are not well documented. Revel (1972) provides brief descriptions of some seral ecosystems in the SBS, and Harcombe (1978) has outlined some seral pathways in the same zone. Descriptive accounts of forest succession in the eastern Rocky Mountains (likely to be classified as ESSF in British Columbia) are given by Cormack (1953), Day (1972), and Corns and LaRoi (1976). In the United States, ESSF-like ecosystems have been described in some detail by Stickney (1980), Davis et al. (1980), and Arno (1982).

No published description of seral ecosystems in the ICH is available, although work by Habeck (1968), Wittinger et al. (1977), Irwin and Peek (1979), Davis et al. (1980), Stickney (1980), Antos and Habeck (1981), and Zamora (1982) has relevance in this zone. Climax ecosystems in the ICH have been described and silvicultural prescriptions made which reflect the current understanding of seral processes.

Studies in northern British Columbia confirm the importance of successional pathways and identify some biotic and cultural factors of influence. Further information on successional ecosystems is essential for improved management. Pfister (1982) pointed out some of the informational needs which can be satisfied, at least in part, by descriptions and predictions of secondary plant succession. Important informational needs in northern British Columbia are considered here with emphasis on general silvicultural requirements and related forest-management needs.

SILVICULTURAL IMPLICATIONS

The harvesting of forest growth emphasizes the importance of mature or overmature forest age-classes. However, silvicultural practice in British Columbia, and elsewhere (Arno 1982), is focused primarily upon activities in the 20-30-year period following disturbance. Smith (1982) observed that it is the occupational disease of the forester to deal more with regenerating forest stages than final ones. The majority of silviculture expenditures — and thus the priority for silviculture-management information — is in the first 20 years following disturbance. This equates with early successional vegetation complexes.

A major consequence of regeneration delay in the P.G.F.R. is the development of competitive vegetation. This vegetative development is, in part, attributable to site characteristics recognized by the late-successional or climax classificaton. There are, however, a variety of factors, independent of site, which may also be important. These include season and method of harvest, residual species eradication policy, and method of site preparation. A more comprehensive knowledge of successional pathways arising from treatments on a given site is a prerequisite to setting priorities for vegetation management. While the scale of vegetative competition problems exceeds our operational capacity to address them, this need for site- and treatment-specific priority assessment will remain high.

The immediate goal of site preparation is the production of a suitable number of accessible, well-spaced, biologically acceptable planting spots at an appropriate cost. This goal satisfies immediate needs but largely ignores the long-term consequences of site preparation which include effects upon:

1. the development and duration of successional vegetation complexes,
2. soil physical properties influencing in turn soil-development processes and mechanical and hydrologic soil characteristics,
3. site productivity.

Short-term site-preparation effects are generally well known. The middle- and long-term effects can only be evaluated if we have an understanding of expected successional development on the site. A key part of any artificial regeneration program is the monitoring of post-planting survival and growth. Free-to-grow status of planted trees is assessed by surveying plantations and associated competitive vegetation at a single point in time. The timing of these surveys is critical if we are to avoid:

1. costly survey duplication if free-to-grow status has not yet been achieved,
2. assessment errors arising from conferring free-to-grow status to a plantation which subsequently "brushes in," and
3. excessive delay in assigning free-to-grow status.

Plantation surveys to determine free-to-grow status must be timed in accordance to tree- and competitive vegetation-growth dynamics. An improved knowledge of early successional trends on important ecosystems is a valuable tool in this regard.

Predictive models of forest succession allow for integrated long-term forest-management planning. Management activities can be selected and scheduled so as to optimize forest values including those related to timber production, wildlife habitat, range, recreation, and soil and hydrology management. These values can be assessed only if we can predict forest type, floristic composition, stand and community structure and their changes over time.

The risks and effects of soil erosion can be predicted through information or post-disturbance succession. Hydrologists benefit from improved predictions of stand structure, which in turn facilitate assessment of snow and water interception and water use as well as snow accumulation.

Range managers require data on the successional development of forested and nonforested rangeland. This includes the information on changes in stand structure and diversity, species composition, species vigour, and productivity required to predict and assess the quality and quantity of forage.

Information on stand structure, species composition, and areal and spatial diversity over time on different sites allows wildlife managers to evaluate and predict habitat suitability. Major informational needs include stand and layer structure, presence and condition of dead standing and fallen trees, and species composition. These are critical in evaluating thermal cover, hiding cover, nesting habitat, and forage availability.

SUMMARY

The classification of forest ecosystems is a fundamental step in improving the understanding and management of our forest lands. The extension of existing climax-oriented classifications to include predictive models of forest succession is a logical and important development from this classification base. Management decision-making in early successional stages can be referenced to this predictive framework, and a greater confidence and consistency in forest-management decisions generated as a result.

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POTENTIAL USE OF THE ALASKA VEGETATION SYSTEM AS AN INDICATOR OF FOREST SITE PRODUCTIVITY IN INTERIOR ALASKA

Leslie A. Viereck, C.T. Dyrness, and K. Van Cleve

ABSTRACT: Four basic forest site types in interior Alaska are differentiated on the basis of successional and mature vegetation, soil temperature and moisture, and topographic position: (1) upland white spruce (2) floodplain white spruce (3) upland black spruce and (4) lowland black spruce. A number of site factors, including a typical soil profile and biomass accumulation and productivity, are given for each type. Forest productivity is high (238 to 950 $g \cdot m^{-2} \cdot yr^{-1}$) on the two white spruce types and low (72 to 148 $g \cdot m^{-2} \cdot yr^{-1}$) in the black spruce types.

INTRODUCTION

In 1980 "A Preliminary Classification System for Vegetation of Alaska" (Viereck and Dyrness, 1980) was published to meet the need for a statewide vegetation classification system that could be correlated with several other systems used by various agencies and groups in Alaska for inventorying and mapping of vegetation. The classification was developed by aggregating plant communities as the basic unit, it was hierarchical in nature, and it was based primarily on the characteristics of the vegetation. Information on the plant communities was obtained from a complete literature review of published and unpublished descriptions of Alaska vegetation types. The system had five levels with the plant communities as the lowest level. The highest level consisted of five formation classes: forest, tundra, shrubland, herbaceous, and aquatic vegetation.

The classification system has been reviewed by field workers and needed changes made. A revision of the classification was distributed to field workers in May 1981. This revision contained two major changes from the published 1980 version: (1) tundra as a level I formation was discontinued and incorporated into the shrubland and herbaceous vegetation formations and (2) the wetland units were developed more fully and were clearly identified at level IV.

At the Workshop for Alaska Vegetation held in Anchorage in December 1981, the classification was revised to level III, definitions were agreed upon which helped to delineate the major units, and criteria for determining the various levels were discussed. As a result of this meeting, the classification was again revised in May 1982 and widely redistributed to field workers in Federal and state agencies (Viereck, et al. 1981).[1] The present classification has three categories at level I, (table 1) forest, scrub, and herbaceous vegetation, and more closely follows both the UNESCO classification (UNESCO 1973) and that of the resource-evaluation techniques (RET) group in Ft. Collins, Colorado (Driscoll et al. 1983). Level II of the classification further subdivides the vegetation on a number of different criteria including size (i.e., tall, low, and dwarf shrub); broadleaf vs. needleleaf for trees; and graminoid, forb, bryoid, and aquatic for the herbaceous vegetation. For level III, the forest and shrub vegetation is divided primarily by the per cent cover of the canopy with the following classes:

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[1] Unpublished report by L.A. Viereck, C.T. Dyrness and A.R. Batten. 1982 Revision of Preliminary Classification for Vegetation of Alaska. On file at Institute of Northern Forestry, Fairbanks, Alaska. 1982; 72 p.

Table 1--1982 revision of classification system for Alaskan vegetation of level III

Level I	Level II	Level III
1. Forest	A. Needleleaf (conifer) forest	1) Closed needleleaf (conifer) forest 2) Open needleleaf (conifer) forest 3) Needleleaf (conifer) woodland
	B. Broadleaf forest	1) Closed broadleaf forest 2) Open broadleaf forest 3) Broadleaf woodland
	C. Mixed forest	1) Closed mixed forest 2) Open mixed forest 3) Mixed woodland
2. Scrub	A. Dwarf tree scrub	1) Closed dwarf tree scrub 2) Open dwarf tree scrub 3) Dwarf tree scrub woodland
	B. Tall shrub	1) Closed tall shrub scrub 2) Open tall shrub scrub
	C. Low shrub scrub	1) Closed low shrub scrub 2) Open low shrub scrub
	D. Dwarf shrub	1) Closed dwarf shrub scrub 2) Open dwarf shrub scrub
3. Herbaceous	A. Graminoid herbaceous	1) Dry graminoid herbaceous 2) Mesic graminoid herbaceous 3) Wet graminoid herbaceous (emergent)
	B. Forb herbaceous	1) Dry forbs herbaceous 2) Mesic forbs herbaceous 3) Wet forbs herbaceous
	C. Bryoid herbaceous	1) Mosses 2) Lichens
	D. Aquatic (non-emergent) herbaceous	1) Freshwater aquatic herbaceous 2) Brackish water aquatic herbaceous 3) Marine aquatic herbaceous

	Trees	Scrub
	------ Per cent ------	
Closed	60-100	70-100
Open	25-60	25-75
Woodland	10-25	--

Level IV of the classification is based primarily on dominant plant species or a combination of two or more species.

The lowest level, Level V, corresponds to the basic plant community and is named by the dominant or most common or conspicuous species in each of the main layers in the community; for example, *Picea mariana/Betula glandulosa-Ledum groenlandicum/Sphagnum* spp. for an open black spruce type with a shrub understory of resin birch and Labrador-tea and with one or more species of sphagnum as an abundant moss in the forest floor. In most cases, the types are based on published accounts of descriptions of the stands.

This paper will concentrate on only the major forest types from the Fairbanks area of the taiga of interior Alaska. This represents only a fraction of the communities in the area, but reflects the present lack of published descriptions of types in the area. At present, the Institute of Northern Forestry has a data base of over 600 stands – mostly forest stands from interior Alaska, and a synthesis and summary of these data will add greatly to the understanding of forest types in interior Alaska. A paper by Foote (1983) utilizes some of these data in descriptions of plant communities following fire in interior Alaska. A large number of interior Alaska forest types have been described by Yarie (1983). These types are not discussed in this paper.

At present, the following fifty-three communities from the Fairbanks area have been described:

General forest types (level II)	Number of level IV communities
Closed needleleaf forest	6
Open needleleaf forest	10
Woodland needleleaf forest	13
Closed broadleaf forest	9
Open broadleaf forest	4
Mixed closed forest	7
Mixed open forest	4
	53

The total of fifty-three forest communities includes both successional and climax (mature) forest stands. Information from fifteen forest communities is used to characterize the sites described in this paper (table 2). Although the Alaska vegetation classification is based as closely as possible on the vegetation itself, we look upon it as a way to eventually develop a site-type or ecosystem-type (habitat type) classification of an ecological nature that will include important factors of the ecosystem such as soil type and environmental factors.

We have begun to develop the necessary information for such a site-type classification as part of a National Science Foundation funded multidisciplinary study in interior Alaska on the structure and function of black spruce (*Picea mariana* [Mill.] B.S.P.) forest in relation to other fire-effected taiga ecosystems.

STUDY SITES

In addition to the description of a large number of forest stands in the "extensive sites," we designated twenty-one widely scattered sites in this study as "semiintensive sites" and included two transects at the intensive site in our analysis. These sites, all within 50 km of Fairbanks, were selected to represent a spectrum from the coldest sites at tree line and on north-facing slopes to the warmest and driest sites that support tree growth. Stands for which data were available from previous studies were selected whenever possible. The geographic locations of these stands are shown in figure 1, and the relative positions of the stands along a cross section of the floodplain and uplands are shown in figure 2.

In the upland, the warmest, driest, south-facing site is represented by an Aspen/buffaloberry/grass stand on a south-facing bluff above the Tanana River. A young aspen stand and two birch stands represent the deciduous forest successional stage after fire on productive sites. Two white spruce stands 70 and 165 years in age represent later stages in this successional sequence.

Table 2--Forest types of the Fairbanks area discussed in this paper

Level I	Level II	Level III	Level IV	Level V
Forest	A. Needleleaf forest	1. Closed needleleaf forest	a. White spruce	1. *Picea glauca/Rosa acicularis-Viburnum edule/ Hylocomium splendens* community
				2. *Picea glauca/Rosa acicularis-Viburnum edule/ Linnaea borealis/Hylocomium splendens* community
				3. *Picea glauca/Rosa acicularis/Rhytidiadelphus triquetrus* community
			b. Black spruce	1. *Picea mariana/Pleurozium schreberi-Hylocomium splendens* community
			c. Mixed black and white spruce	1. *Picea glauca-Picea mariana/Alnus crispa/ Rhytidiadelphus triquetrus* community
		2. Open needleleaf forest	a. Black spruce	1. *Picea mariana/Ledum groenlandicum-Vaccinium uliginosum/Pleurozium schreberi* community
				2. *Picea mariana/Ledum groenlandicum-Vaccinium uliginosum/ Sphagnum* spp. community
				3. *Picea mariana/Ledum groenlandicum/ Hylocomium splendens* community
				4. *Picea mariana/Ledum groenlandicum/Pleurozium schreberi* community
				5. *Picea mariana/Salix planifolia/Ledum groenlandicum/Sphagnum* spp. community
		3. Needleleaf woodland	a. Mixed spruce	1. *Picea glauca-P. mariana/Alnus crispa-Betula glandulosa/ Pleurozium schreberi* community
	B. Broadleaf forest	1. Closed broadleaf forest	a. Quaking aspen	1. *Populus tremuloides/Viburnum edule/Linnaea borealis* community
			b. Paper birch	1. *Betula papyrifera/Alnus crispa/Calamagrostis canadensis* community
			c. Balsam poplar	1. *Populus balsamifera/Alnus tenuifolia/ Rosa acicularis/ Equisetum* spp. community
		2. Open broadleaf forest	a. Quaking aspen	1. *Populus tremuloides/Shepherdia canadensis/ Calamagrostis purpurescens* community

The series of floodplain stands represents mid to late stages of a successional sequence developing on newly exposed silt on both the Chena and the Tanana Rivers. Younger forest stages include balsam poplar stands of varying ages. The mature, productive white spruce stands include two 100-120- year-old stands and one 250-year-old stand. Older stages on terraces underlain by permafrost include a mixed black and white spruce stand and three black spruce stands. Open and closed stands of black spruce with feathermosses or sphagnum, most of which are underlain by permafrost, are representative of the colder upland sites. The coldest site was a white spruce-black spruce/alder-shrub birch/feathermoss type at tree line at an elevation of 750 m.

METHODS

The methods used in this study of twenty-three stands are reported by Viereck et al. (1983) who describe the vegetation and soils in detail. Biomass and productivity were determined for selected stands only (a total of fifteen for this paper). Microclimate measurements were concentrated in soil temperatures at most of the sites. Soil moisture was determined by weekly gravimetric samples and averaged for the growing season. We found that soil temperature was a better indicator of site than air temperature. As a comparison index, we developed a soil degree-day accumulation index for each stand based on a 10-cm depth, 0°C as a base, and the period from May 20 to September 10. The index ranged from 2200 for the aspen stand on the south-facing bluff to 483 for a north slope, black spruce stand underlain by permafrost.

DESCRIPTION OF SITE TYPES

The forest sites separated into two distinct groups along the environmental gradient of soil moisture and soil tempera-

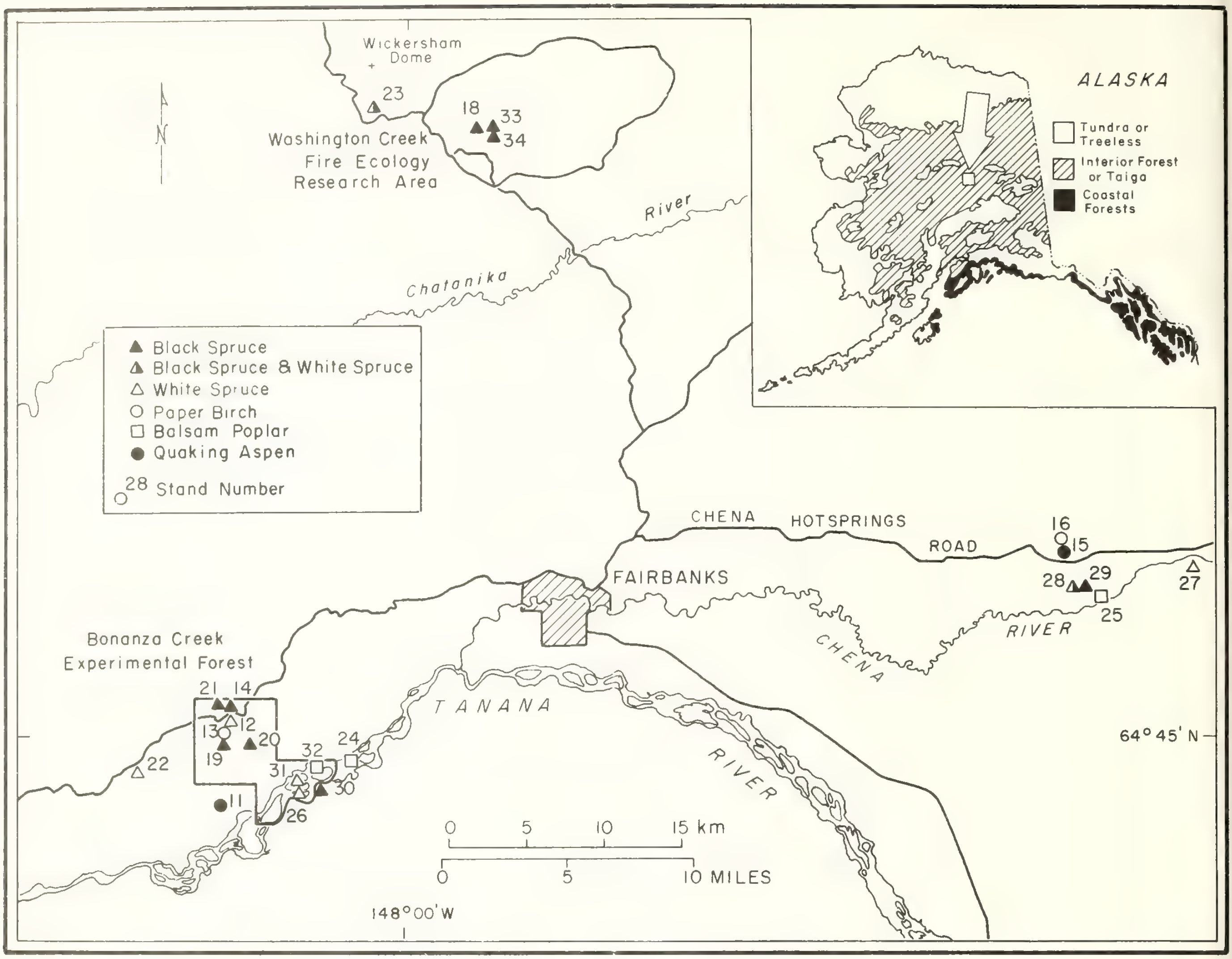

Figure 1.--Location of twenty-one semiintensive sites (stands 11-16 and 18-22) and the intensive site (stands 33 and 34) in the Fairbanks area of interior Alaska (from Viereck et al. 1983).

ture (fig. 3). The group of stands on warm mesic sites has an above-ground tree productivity of over 200 $g \cdot m^{-2} \cdot yr^{-1}$ and is dominated by white spruce in the mature stages. The group of stands on cold, wet sites has a low productivity of under 200 $g \cdot m^{-2} \cdot yr^{-1}$, is usually underlain by permafrost, and is dominated by black spruce in later stages of succession (fig. 4). The productive forest sites can be further subdivided into two forest site types based on parent material and topographic position: (1) upland sites with thick loess deposits on slopes that tend to be south-facing, and (2) floodplain sites adjacent to the rivers that have developed on recently formed alluvium (fig. 3). The successional sequences in these two site types leads to white spruce stands but are different in vegetation components and developmental processes.

The low-production, black spruce sites are also found in two topographic settings: (1) upland, north-facing slopes on loess and coluvium or any slope at higher elevations or on shallow soils, and (2) lowland sites on old river terraces and in valley bottoms. Although a number of distinct black spruce forest types are found on these two site types, we could determine no distinct separation by vegetation type. Successional stages leading to mature black spruce stands can be similar on both upland and lowland sites. Because of these similarities, we have separated these two types primarily on the basis of topographic position rather than vegetation composition, although analysis of a larger number of stands may show distinct differences in the communities on the two sites.

Upland Mesic White Spruce Site

Description of the site type.--This site type occupies the mesic, south-facing, loess-covered slopes adjacent to the Tanana River to an elevation of at least 400 m. In our study, it was represented by two successional, closed broadleaf forest communities and one closed white spruce forest community.

1. Closed *Populus tremuloides/Viburnum edule/Linnaea borealis* community,
2. Closed *Betula papyrifera/Alnus crispa/Calamagrostis canadensis* community and one spruce type, and
3. Closed *Picea glauca/Rosa acicularis-Viburnum edule/ Hylocomium splendens* community.

The type is represented by three soil series: Gilmore, Steese, and Fairbanks, all of which are classified as Alfic cryochrepts. Soils supporting upland white spruce were found to be among the warmest and best drained soils in the area. The following is a generalized description of a profile typical of Fairbanks silt loam:

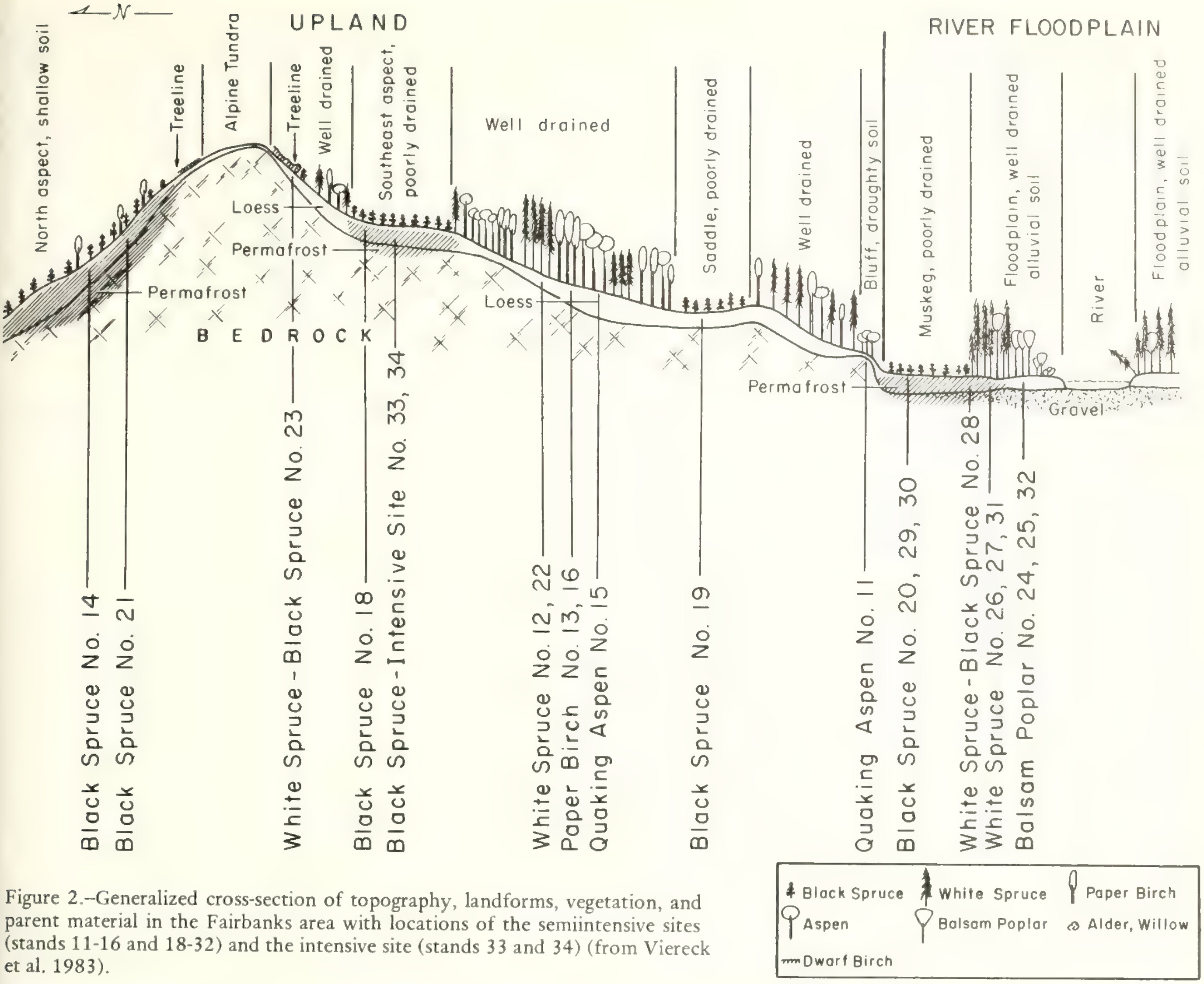

Figure 2.–Generalized cross-section of topography, landforms, vegetation, and parent material in the Fairbanks area with locations of the semiintensive sites (stands 11-16 and 18-32) and the intensive site (stands 33 and 34) (from Viereck et al. 1983).

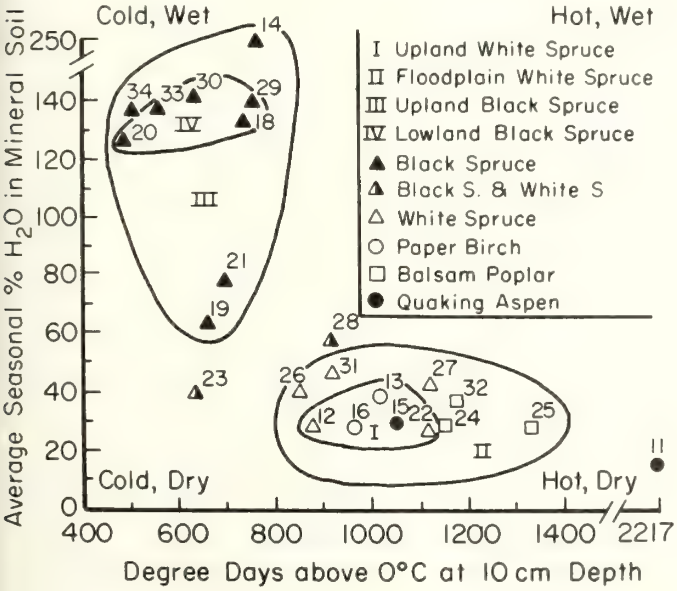

Figure 3.–Location of site and forest types along an environmental gradient determined by accumulated soil-degree days and average seasonal moisture in the mineral soil (from Viereck et al. 1983, modified).

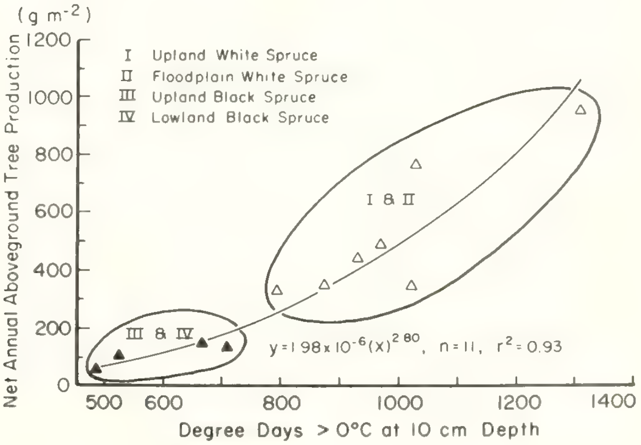

Figure 4.–Net, annual, above-ground, tree-biomass production as related to degree-day accumulations of black spruce and white spruce sites in interior Alaska (from Viereck and Van Cleve 1984, modified).

01	8 to 5 cm	Live moss and recently deposited litter.
021	5 to 0 cm	Dark brown mat of coarse fibrous moss remains and forest litter; roots abundant.
A1	0 to 4 cm	Dark brown (10YR 3/3) silt loam; weak granular structure; friable; roots abundant.
A3	4 to 10 cm	Brown (10YR 4/3) silt loam; moderate subangular blocky structure; friable; roots abundant.
B1	10 to 25 cm	Brown (10YR 4/3) silt loam; weak subangular blocky structure; friable; roots common.
B2	25 to 30 cm	Dark yellowish brown (10YR 3/4) silty clay loam; weak platy structure; firm; roots common.
C1	30 to 39 cm	Brown (10YR 4/3) silt loam; platy structure; slightly firm; roots common.
C2	39 to 100 cm+	Dark grayish brown (2.5YR 4/2) silt loam; weak platy structure; friable; roots common, decreasing with depth.

During the period of our study, the average soil degree accumulation ranged from 876 to 1117, and the average soil moisture in the upper 15 cm of mineral soil ranged from 25 to 40 per cent. The average soil temperature for the growing season at 10 cm ranged from 8 to 10°C. Forest-floor thickness on the sites ranged from 2 cm in the aspen stands to 9 cm in the spruce stands. The pH of the forest floor ranged from 5.8 and 5.6 for the aspen and birch stand to 6.0 for the white spruce stand. The sites were all free of permafrost.

On this site type, tree development and productivity are high. Aspen and birch reach heights of 20 m and diameters of 25 cm in 80 to 100 years. Basal area of aspen and birch stands is approximately 30 to 35 $m^2 \cdot ha^{-1}$ in the mature stands. In mature spruce stands, which usually have a closed canopy, trees may reach heights of 25 to 30 m and diameters of 25 to 35 cm. Basal areas range from 40 to 60 $m^2 \cdot ha^{-1}$.

Standing above-ground tree biomass ranged from 9,200 to 18,300 $g \cdot m^{-2} \cdot yr^{-1}$ for the hardwood stands and 24,900 $g \cdot m^{-2}$ for one spruce stand. Annual above-ground tree biomass productivity ranged from 343 to 760 $g \cdot m^{-2} \cdot yr^{-1}$ for the hardwood stands and was 353 $g \cdot m^{-2} \cdot yr^{-1}$ for the spruce stand.

The main shrub species in the mature spruce stands are scattered alders (*Alnus crispa* [Ait.] Pursh.), prickly rose (*Rosa acicularis* Lindl.), and highbush cranberry (*Viburnum edule* [Michx.] Raf.). Low shrubs and herbs are sparse to occasional, depending on overstory canopy, and consist primarily of twinflower (*Linnaea borealis* L.), horsetails (*Equisetum* spp.), and northern comandra (*Geocaulon lividum* [Richards.] Fern.). The forest floor has a nearly continuous mat of *Hylocomium splendens* (Hedw.) B.S.G.

Successional sequence.-- Following fire, the usual pattern of plant invasion is by species with light, wind blown seed, such as fireweed (*Epilobium angustifolium* L.) and willow shrubs, especially *Salix bebbiana* Sarg. and *S. scouleriana* Barratt. A number of species resprout from stumps or roots, especially highbush cranberry, rose, willows, alder, aspen, and birch. A few species develop from seed apparently left unburned in the soil — *Geranium bicknellii* Britt., *Corydalis sempervirens* (L.) Pers., and *Rubus idaeus* L. The next stage in the developing vegetation is dominated by shrubs, primarily willows, and by deciduous tree saplings. Spruce seedlings may be present at this time but their slow growth makes them relatively inconspicuous in the stand.

In the dense hardwood stage, young aspen and birch trees form a dense canopy that tends to shade out the understory that develops following fire. Heavy litterfall prevents the development of a moss layer, but moss species of the mature forest stages, such as *Hylocomium splendens* and *Pleurozium schreberi* (Brid.) Mitt., become scattered on elevated areas such as fallen logs. This stage usually occurs during the period of 25 to 50 years following the fire. For the next 50-100 years, deciduous trees dominate the site, although white spruce may become conspicuous in the understory. Both the aspen and birch stands become more open with age, and the density drops to about 700 trees per ha for aspen and 300 to birch. At about 100 years after a fire, white spruce becomes dominant, often with a component of birch and aspen. As the stands become older, the hardwoods are less abundant. The greatest change is the development of a continuous mat of feathermoss, primarily *Hylocomium splendens*. The mature spruce stage, with scattered remnants of birch and a well-developed moss mat and organic layer, is reached at about 200 years following a fire.

Floodplain White Spruce Site

Description of the site type.--This site type occupies the floodplains adjacent to the major rivers of interior Alaska. We examined forest stands along both the Chena River and the Tanana River between 120 and 180 m elevations. In our study, the site type was represented by one successional community and two white spruce communities:

1. Closed *Populus balsamifera/Alnus tenuifolia-Rosa acicularis/Equisetum* community,
2. Closed *Picea glauca/Rosa acicularis-Viburnum edule/ Linnaea borealis/Hylocomium splendens* community, and
3. Closed *Picea glauca/Rosa acicularis/Rhytidiadelphus triquetrus* community.

The young soils on floodplains immediately adjacent to the rivers are of the Salchaket series and are classified as Typic Cryfluvents. Soils supporting floodplain white spruce are formed in alluvium that is well drained and free of permafrost. The soils occur on level floodplains and terraces adjacent to the major rivers, and profiles often reflect the effects of repeated flooding episodes. The following is a typical profile in the Salchaket series (Typic Cryofluvent) supporting a mature stand of white spruce:

01	13 to 9 cm	Live feathermoss, moss remains, and recently deposited litter; lower portion is mixed light gray silt from recent flooding.
021	9 to 3 cm	Partially decomposed moss remains; mixed with small amounts of light gray silt; roots abundant.
022	3 to 0 cm	Black (10YR 2/1) humus; roots abundant.
C1	0 to 9 cm	Dark grayish-brown (10YR 4/2) very fine sandy loam; distinct medium and fine gray (10YR 5/1) and yellowish-brown (10YR 5/6) mottles; weak subangular block structure; friable; roots common.
C2	9 to 16 cm	Dark grayish brown (2.5YR 4/2) silt loam; weak subangular blocky structure; friable, roots common; horizon contains many lenses and pockets of organic material as a result of past flooding.
C3	16 to 32 cm	Olive brown (2.5Y 4/4) very fine sandy loam; weak fine platy structure; friable; roots few.
C4	32 to 90 cm	Grayish brown (2.5Y 5/2) medium sand; single grained; loose; very few roots; water-worn gravels at about 180 cm.

During the period of our study, average soil moisture ranged from 30 to 50 per cent and soil degree sums from 800 to 1310, giving an average soil temperature at 10 cm for the growing season of 7.0°C to 11.6°C. Forest-floor thickness varied from 5 to 7 cm in the balsam poplar stands to 18 cm in the white spruce stands. The pH of the forest floor was 6.2 for the balsam poplar stands and 5.6 for the white spruce stands.

Tree productivity is highest on these floodplain sites. Balsam poplar may reach heights of 25 m and diameters of 25 cm in 60 years. Because of the low densities of the trees, about 650 stems per ha in older stands, basal area is usually under 40 $m^2 \cdot ha^{-1}$. In the mature white spruce stands, tree heights of 30 m are common, and diameters at 120 years average 30 cm. Basal area of the floodplain stands of white spruce ranged from 40 to 58 $^2 \cdot ha^{-1}$.

Standing crop of above-ground tree biomass ranged from 4,000 to 18,000 $g \cdot m^{-2}$ for balsam poplar stands to 6,000 to 24,500 for white spruce stands. Annual, above-ground tree biomass productivity ranged from 264 to 952 $g \cdot m^{-2} \cdot yr$ for the balsam poplar stands and 240 to 540 $g \cdot m^{-2} \cdot yr$ for the white spruce stands.

The main shrub species in this site type are alders (*Alnus tenuifolia* Nutt.) and willows (primarily *Salix alaxensis* [Anderss.] Cov.) in the early successional stages, but, in the mature stands, *Alnus crispa* may replace *Alnus tenuifolia*, and the willows are largely replaced by *Viburnum edule* and *Rosa acicularis*. A wide variety of herbs occurs in the earlier successional stages but are replaced largely by orchids and *Pyrola* species in the mature stands. Low and dwarf shrubs are lacking in early stages but *Linnaea borealis, Empetrum nigrum* L., and *Vaccinium vitis-idaea* L. are common in the mature spruce stands. The feathermoss, *Hylocomium splendens,* is the typical forest floor moss, but in some stands it is largely replaced by *Rhytidiadelphus triquetrus* (Hedw.) Wornst., perhaps as a result of occasional flooding.

Successional Sequence.–Succession on recently deposited alluvium on the floodplains of the major rivers in interior Alaska is a primary succession sequence. Succession begins with the invasion of willow species, which are usually followed by alder, and eventually develop into a closed shrub stage. A number of physical, chemical, and biological factors, including frequency of flooding, seed source, height above the river, are all important in these early successional stages. Balsam poplar, a fast-growing, floodplain species forms the next successional stage. During this stage, forest productivity is high, litterfall large, and soil temperatures relatively warm. Willows and alders persist into the balsam poplar stage as a well-developed shrub layer but gradually thin out as the tree canopy closes. Other shrubs, especially *Rosa acicularis* and *Viburnum edule*, develop under the poplar canopy. The herbaceous layer, well developed in early successional stages, continues in the poplar stage primarily as a thin mat of *Equisetum pratense* Ehrh. Establishment of white spruce may occur during the shrub stage or during the balsam poplar stage. The stands next develop into mixed white spruce-balsam poplar stands and finally into well developed spruce stands.

Following the initial white spruce stands, succession is somewhat variable and poorly documented. The white spruce stands may persist through several generations or may be replaced by black spruce after the first generation. Eventually, on the older terraces, soil temperatures become colder, permafrost is established, and the white spruce stands are replaced by black spruce.

Upland Black Spruce Site Type

Description of the Site Type.–The site type we have designated as the upland black spruce site type is variable and will undoubtedly be further subdivided as more detailed information becomes available. The sites were primarily on ridge tops or north-facing slopes from elevations of from 385 to 470 m. Two stands at the intensive site at Washington Creek had a 10 per cent slope with a southeast aspect.

The forest communities on the sites are generally open to closed black spruce stands that were subdivided into a number of community types but which seem to fit into three broad community types:

1. Closed *Picea mariana/Pleurozuim schreberi-Hylocomium splendens* community,
2. Open *Picea mariana/Ledum groenlandicum-Vaccinium uliginosum/Pleurozium schreberi* community, and
3. Open *Picea mariana/Ledum groenlandicum-Vaccinium uliginosum/Sphagnum* community.

On some slopes the *Pleurozium*-dominated community on the upper slopes gradually grades into the *Sphagnum* type on the lower slopes (Dyrness and Grigal 1979).

The upland black spruce type was found on four soil series: the Ester, Fairplay, Gilmore, and Saulich, which are classified as Histic Pergelic Cryaquepts, Aquic Cryorthents, or Alfic Cryochrepts. Of the six stands that we studied in this type, three were underlain by permafrost, and three were classified as permafrost-free although the bedrock beneath the shallow soil mantle may have been frozen.

The soils supporting upland black spruce were found to be the wettest and coldest of all those soils supporting tree growth. Although these conditions may generally be attributed to very thick forest floors and the consequent appearance of shallow permafrost, they also exist in certain soils on upper slopes and ridgetops that lack permafrost. The following is a generalized profile description from the intensive study site at Washington Creek and is representative of the Saulich soil series:

01	25 to 18 cm	Live moss and recently deposited litter.
021	18 to 5 cm	Dark reddish-brown (5YR 3/2) mat of coarse, fibrous moss remains and forest litter; roots abundant.
022	5 to 0 cm	Black (5YR 2.5/1) humus; roots abundant.
A1	0 to 7 cm	Very dark grayish-brown (10YR 3/2) silt loam; weak subangular blocky structure; friable; roots common.
C	7 to 25 cm	Dark grayish-brown (2.5YR 4/2) saturated silt loam; many distinct dark yellowish-brown (10YR 4/4) mottles; massive, sticky and plastic; roots scattered.
	25 cm+	Permafrost.

Soil moisture in the mineral soil varied from 60 per cent in the permafrost-free sites to 250 per cent in one site with a shallow active layer. At 10 cm, soil degree-day sums ranged from 490 to 760, giving an average temperature at 10 cm during the growing season of 4.4 to 6.7°C. The organic layer is thick in all of the stands in this type but varied from 17 to 38 cm. The pH of the forest floor was 4.2. In the stands underlain by permafrost, the thickness of the active layer varied from 22 to 51 cm.

Tree development and productivity is low for all of the upland black spruce sites. Tree density is variable – from 1,400 to 4,000 stems per ha. Tree heights in mature stands range from 7 to 15 m and diameters from 6 to 15 cm. Basal areas range from 7 to 27 $m^2 \cdot ha^{-1}$ with an average for the six stands of 14 $m^2 \cdot ha^{-1}$. Standing crop and productivity are low in these stands. The standing tree biomass ranged from 2,323 to 10,756 $g \cdot m^{-2}$ and annual above-ground tree biomass production from 102 to 148 $g \cdot m^{-2} \cdot yr^{-1}$. The highest values were from a ridgetop permafrost-free site at Bonanza Creek.

The common low shrubs in these open and closed black spruce stands are *Vaccinium vitis-idea, V. uliginosum* L., and *Ledum groenlandicum* Oeder. The dominant moss in these sites is *Pleurozium schreberi*, but there is also a large component of *Hylocomium splendens* in the drier sites and *Sphagnum* spp. in the wetter sites. Lichens, primarily *Cladonia* spp. *Peltigera* spp., and *Nephroma arcticum* (L.) Torss., are common in the stands and can have up to 50 per cent cover in the open stands.

Revegetation Following Fire.--Revegetation following fire in the upland black spruce type is usually rapid. Within weeks of the fire, sprouts from roots and rhizomes of shrubs and herbs are abundant. Even when burning is severe and all underground parts are killed, invasion by mosses and liverworts and the establishment of seedlings is usually accomplished by the spring of the year following the fire. Areas of bare mineral soil are covered with liverworts and mosses, especially *Marchantia polymorpha* L. and *Ceratadon purpureus* (Hedw.) Brid., and herbaceous species with light, airborne seeds such as *Epilobium angustifolium*. Spruce seedlings may become established at this time. Plant cover during this stage increases quickly to as much as 40 to 50 per cent. In the shrub stage, which lasts from 6 to 25 years following the fire, willows and alders dominate the vegetation but herbaceous species remain abundant.

The tree canopy of black spruce begins to dominate at 25 to 30 years following the fire. The young stands of 40 to 60 years are dense, with as many as 4,000 to 6,000 trees and saplings per ha. The most significant event that occurs during this stage is the invasion and rapid development of the feathermosses, *Hylocomium splendens* and *Pleurozium schreberi*, which along with *Sphagnum* species may develop as much as 50 per cent cover. With the establishment of the mosses, the development of a thick organic layer begins, and the depth to permafrost decreases. Once the tree canopy is well established, changes in the vegetation sequence are slower and more subtle. During the older stages, the tree canopy is mostly closed although the density is less than in previous stages, averaging 2,200 stems per ha. The moss layer remains about the same as in the younger stages except for a decline in foliose lichens and an increase in feathermosses, sphagnum, and fruticose lichens. The development of the black spruce type into a mature stand of over 100 years follows without any major changes in vegetation composition.

Lowland Black Spruce Type

Description of the Site Type.--This type occupies the old terraces of the major rivers and small valley bottoms along drainages in the uplands. Only three of the semiintensive sites were in this type, and all were on older terraces of the Tanana and Chena Rivers at elevations of from 120 to 170 m. The forest communities on these sites are similar to those of the uplands but were separated into three community types based on differences in the shrub and moss layers. The communities are:

a. Open *Picea mariana/Ledum groenlandicum/Hylocomium splendens* community type,

b. Open *Picea mariana/Ledum groenlandicum/Pleurozium screberi* community type, and

c. Open *Picea mariana/Salix planifolia/Ledum groenlandicum/Sphagnum* community type.

The lowland black spruce type is found on the Goldstream and Bradway soil series which are classified either as Histic Pergelic Cryaquepts or as Pergelic Cryaquepts. Soils supporting the lowland black spruce are wet and poorly drained. These soils are generally formed in alluvium with permafrost at a shallow depth. A generalized description of a profile typical of Goldstream silt loam (Histic Pergelic Cryaquept follows).

01	30 to 18 cm	Live moss, moss remains, and recently deposited litter.
02	18 to 0 cm	Black (10YR 2/1) humus; roots abundant.
B21g	0 to 10 cm	Dark gray (5YR 4/1) silt loam; coarse, distinct dark brown (10YR 4/3) mottles; massive; friable; roots common.
B21g	0 to 10 cm	Dark gray (5YR 4/1) silt loam; coarse, distinct dark brown (10YR 4/3) mottles; massive; friable; roots common.
B22g	10 to 15 cm	Dark greenish-gray (5GY 4/1) saturated silt loam; common, medium distinct dark grayish-brown (2.5Y 4/2) mottles; massive; friable; few roots.
	15+ cm	Permafrost.

All three stands studied were underlain by permafrost and had active layer thicknesses varying from 16 to 55 cm. The forest-floor organic layer ranged from 14 to 25 cm in thickness and had a pH of 4.2. Lowland black spruce stands are usually open with trees ranging in height from 8 to 15 m and diameters from 5 to 15 cm. Tamarack (*Larix laricina*) occurs occasionally in the lowland stands along with scattered birch. Basal areas tend to be slightly higher in the lowland black spruce stands than in the upland stands with a range of 8 to 40 $m^2 \cdot ha^{-1}$ and an average in the three stands studied of 20 $m^2 \cdot ha^{-1}$.

Whole tree biomass for the one stand that we studied in the lowland was 1,492 $g \cdot m^{-2}$ and annual, above-ground, tree biomass productivity was only 72 $g \cdot m^{-2} \cdot yr^{-1}$. The shrub and forest-floor vegetation of the lowland stands is very similar to that of the upland stands. *Ledum groenlandicum* is more abundant in the lowland stands, but *Vaccinium uliginosum* and *V. vitis-idaea* have about the same cover in both types. Species of *Salix*, especially *Salix planifolia* Pursh. spp. *pulchra* (Cham.) Argus, are more common in lowland than upland sites. As with upland sites, the lowland sites show a variation in moss species from *Hylocomium splendens* on the driest sites to *Sphagnum* spp. on the wet sites but with *Pleurozium schreberi* the dominant moss in most stands.

Successional Sequence.--The successional sequence on the lowland black spruce sites seems to be similar to that of the upland sites; therefore the sequence is not repeated here.

Other Site Types

The four site types that we describe above occupy most of the forested terrain in the Fairbanks area. It should be emphasized, however, that there are a number of other site types and transitions within the region. For some of the site types, we have begun to gather soils and environmental information. For example, one of our sites was an aspen stand on a steep, south-facing bluff that we considered to be at the extreme limit of tree growth in the area. This site was occupied by a *Populus tremuloides/Shepherdia canadensis/Calamagrostis purpurescens* community. Soil degrees were over 2,200, and soil

Table 3--Selected site factors for four forest types in interior Alaska

Forest types	Soil series	Soil classification	Parent material	Drainage class	Forest floor thickness	Depth to permafrost	Soil degree days	Ave. growing-season soil temperature at 10-cm depth
					(cm)	(cm)		(°C)
Upland white spruce and successional series (aspen and birch)	Gilmore Steese Fairbanks	Alfic Cryochrept Alfic Cryochrept Alfic Cryochrept	Loess	Well drained	2-9	none	876-1117	8-10
Floodplain white spruce and successional series	Salchaket	Typic Cryofluvent	Alluvium	Well drained	4-9	none	799-1310	7-12
Upland black spruce	Ester Saulich Fairplay Gilmore	Histic Pergelic Cryaquept Histic Pergelic Cryaquept Aquic Cryorthent Alfic Cryochrept	Loess	Poorly drained	12-38	22 to 50 or none	563-761	5-7
Lowland black spruce	Goldstream Bradway	Histic Pergelic Cryaquept Pergelic Cryaquept	Alluvium	Poorly drained	14-25	16-55	483-729	4-6.5

Table 4--Above-ground tree biomass and annual, above-ground, tree-biomass production for four forest types in interior Alaska

		Tree biomass ($g \cdot m^{-2}$)		Annual tree production ($g \cdot m^{-2}$)	
Forest Types	No. of stands	Range	x + SE	Range	x + SE
Upland white spruce site:					
White spruce	1	24,940	--	353	--
Aspen	1	18,310	--	760	--
Birch	3	9,192-14,713	11,156±1,782	343-572	470±67
Floodplain white spruce site:					
White spruce	3	6,216-24,443	15,387±5,262	238-540	370±89
Balsam poplar	3	4,067-18,027	12,097±4,165	264-952	552±206
Upland black spruce site:					
Black spruce	3	2,323-10,756	6,143±7,467	102-148	127±14
Lowland black spruce site:					
Black spruce	1	1,492	--	72	–

moisture averaged only 20 per cent for the season. *Shepherdia canadensis* (L.) Nutt. and *Arctostaphylos uva-uris* (L.) Spreng. are indicator species of this dry site type. At the colder, dry end of the environmental scale, we selected a white spruce-black spruce woodland at treeline at 750 m which we classified as *Picea glauca-Picea mariana/Alnus crispa-Betula glandulosa/ Pleurozium schreberi* community. Although air temperature at this site was lower than at all the other sites, soil degree-day accumulations were not as low as at some of the lowland black spruce sites. The dominance of *Betula glandulosa* Michx. in the shrub layer is typical of the open and woodland spruce stands at treeline.

SUMMARY AND CONCLUSION

Forest sites in the taiga of interior alaska extend over a wide environmental gradient but basically can be divided into cold, black spruce sites, usually underlain by permafrost, and mesic white spruce sites and successional stages leading to white spruce on warm, well-drained, permafrost-free soils. Each of these basic types can be further subdivided on the basis of topographical position, developing vegetation sequence, and mature vegetation. The four basic site types described in this paper are: (1) upland white spruce sites, (2) floodplain white spruce sites, (3) upland black spruce sites, and (4) lowland black spruce sites. For each of these site types, there are a number of successional and climax-forest communities, soil types, typical and indicator species, and environmental factors that can be used to distinguish and describe the types. Some of these site factors are summarized in table 3. Forest productivity is high on the two white spruce site types and low on the black spruce types (table 4).

Forest management should be concentrated on the more-productive sites. Each of these sites has its own unique management and regeneration problems, and forest management plans will have to be developed for each site type.

The Alaska Vegetation Classification System provides a framework for the recognition and classification of forest site types in interior Alaska, but, because the Alaska taiga flora is made up of a few species with wide ecological amplitude, vegetation alone is not enough for separating differences in site factors. This seems to be especially true with the black spruce types, which are found over a wide variety of soil types. Data such as those presented in this paper should be accumulated on site factors related to each of the vegetation communities so that the information can serve as a basis for classification of ecosystem types (similar to the habitat types of Daubenmire) which can then be used as basic management units. When these units are established and identified, they will be useful for the formulation of management practices, especially as the types relate to forest productivity and regeneration following logging or other disturbance for the principal forest sites in interior Alaska.

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SITE CLASSIFICATION AND REGENERATION PRACTICES ON FLOODPLAIN SITES IN INTERIOR ALASKA

John C. Zasada

INTRODUCTION

The floodplains of Alaska's rivers are some of the most productive forest sites in the state. Historically these forests, in particular white spruce (*Picea glauca*), were heavily utilized during the gold rush and settlement period of the early 1900s. As transportation of building and heating materials from outside of Alaska became more efficient, local forest utilization decreased. Present utilization is insignificant except near villages where forests are the only readily accessible source of wood. There is high potential to increase utilization of these stands. The impetus for this increase appears to stem from political and economic interest.

Management experience and research information that can be applied to management of floodplain sites is limited. The most detailed research on any aspect of management on northern river floodplains (north of 60° N latitude) was reported by Gardner (1983) for the Liard and Meister rivers in southern Yukon. Ganns (1977) reported on regeneration studies on Tanana River (Alaska) sites. Experience gained from management on uplands in Alaska provides some insight into management alternatives for flood plains. However, ecological conditions on these two physiographically distinct areas are different in several important ways, and practices may not be directly transferable from one type of area to the other (Zasada et al. 1977).

In contrast to the lack of management experience is the availability of a relatively large body of basic ecological information for flood plain sites (Viereck 1970a, 1970b; Van Cleve et al. 1971, 1980; Van Cleve and Viereck 1972, 1980; Juday and Zasada 1984). These studies provide valuable information on site development and forest succession. However, they do not deal with secondary forest succession following such disturbances as fire and harvesting.

The purpose of this paper is to consider factors that affect white spruce regeneration on flood plains. To do this, we first need to consider, briefly, the development of forests on these sites — how white spruce stands originate and their fate in the absence of disturbance. In the second part of this paper, regeneration alternatives will be discussed using the Willow Island research project as an example. This project is primarily concerned with regeneration options following harvesting, but white spruce stand and site development have also been examined in some detail (Juday and Zasada 1984).

PRIMARY FOREST DEVELOPMENT

Floodplain sites are dynamic in terms of vegetation change and soil development. These changes are described briefly below. Unless otherwise noted, the following summary is distilled from Viereck (1970a and 1970b), Van Cleve et al. (1971, 1980), Van Cleve and Viereck (1972, 1980), and Juday and Zasada (1984).

Forest development on floodplain sites begins with the deposition of a gravel/silt bar that remains stable long enough for vegetation to become established. Various willows (*Salix* spp.) and alder (*Alnus incana*) are the first woody plants to dominate the site. Balsam poplar (*Populus balsamifera*), which becomes established at about the same time as the willows and alder, assumes a dominant or codominant position about 15 to 20 years after site formation; it remains the dominant species for 50 to 60 years. Seedlings of other trees, e.g., aspen (*Populus tremuloides*), birch (*Betula papyrifera*), tamarack (*Larix laricina*), and white spruce may be present to varying degrees in these early stages of development but either die or do not become important until much later in forest development[1] (Krasny 1982).

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[1] Marianne Krasny, College of Forest Resources, University of Washington, Seattle, WA, personal communication.

Generally, white spruce becomes the dominant species at 80 to 100 years. There are, however, cases where balsam poplar is dominant for at least 200 years. White spruce invades sites early in forest development, but many early seedlings probably die as a result of flooding or other disturbance, and the time at which spruce becomes a permanent component of the developing forest varies with site conditions. Nanson and Beach (1977) reported that conditions on floodplain sites in north-central British Columbia may not be favorable for white spruce establishment until well into the balsam poplar stage.

The first generation of white spruce on these sites may dominate for 200 to 300 years. During this time there is continual attrition, with some replacement of dominants as suppressed and intermediate trees are released. Trees are relatively even-aged for the first 100 to 150 years. However, as the oldest trees in the stand attain ages of 250 to 300 years, the difference in age of dominants and codominants may be as much as 100 years. The number of cycles or generations of white spruce that can occur on a given floodplain site in interior Alaska is not known. Nanson and Beach (1977) reported that three to four distinct generations of white spruce may have occupied a given site in British Columbia.

Regeneration is primarily from seed that germinates on a variety of surfaces: silt deposited by flooding, rotted wood, or mineral soil exposed by windthrows. Layering was reported by Densmore (1980) on the floodplain of the upper Dietrich River, Alaska; both vegetative and seed reproduction were present. This site is near treeline in the Brooks Range.

White spruce stands are subjected to several types of disturbance which have different impacts on tree and stand development. The most serious threat to stand integrity is erosion by the river and ultimate destruction of the stand. White spruce sites do not appear to erode as rapidly as younger sites but may be subjected to continuous bank erosion. For example, it is not uncommon to find erosion of 50 to 100 feet of river bank in one year on sites where willow, alder, and/or balsam poplar predominate. On sites where spruce dominates, erosion probably does not exceed 5 to 10 feet per year.

Stands are flooded periodically. Frequency of flooding is determined by terrace height and river levels. Because white spruce stands are on higher terraces, they are flooded less frequently than stands in earlier stages of development. Some of the most severe flooding occurs in stands situated where ice jams that form downriver cause high river levels upstream. In one instance on the Yukon River (several miles downstream from the Charley River), water level was 15 to 20 feet above normal summer levels as a result of ice jamming downstream. Trees along the edge of the river had substantial stem damage 5 to 10 feet above ground because of ice abrasion.

Flooding occurs at different times of year. For example, on the Tanana River, flooding may occur in late spring or early summer as a result of annual snowmelt and spring runoff, and again in late summer or early fall as the result of heavy rains.

Fire may also affect these stands, even though they tend to be protected by river channels and old sloughs. On the 1977 500,000-acre Bear Creek fire, I observed wildfire in floodplain stands along the Kuskokwim River. Older evidence of burning comes from Willow Island on the Tanana River floodplain. Here fuel sampling revealed significant amounts of charcoal from past fires in the organic layers and on the surface of the mineral soil on one of the oldest sites on the island.

Black spruce (*Picea mariana*) ultimately invades these sites, but the time required for this species to replace white spruce and the influence of the various disturbances is not known, nor is the invasion and establishment process fully understood. It is commonly believed that black spruce invades late in succession, when white spruce is deteriorating. However, I have found scattered black spruce in relatively vigorous 100- to 150-year-old white spruce stands, indicating that establishmen can occur before the first generation of white spruce has begu to deteriorate. Paper birch can also become an important component in older white spruce stands. Paper birch, like black spruce, has been found in younger stands, suggesting that in some cases establishment may occur at about the same time as white spruce.

As mentioned earlier, soil changes occur in concert with the vegetation changes. Early in primary succession, the river is th predominant force in soil development. Later in succession, vegetation becomes a relatively more important factor. As vegetation develops, terraces are stabilized, soil is retained, anc soil fertility is altered. The soil surface (seedbed) changes from almost pure mineral soil to a well-developed organic forest floor; intermediate conditions include various combinations of silt and organic matter. The developing organic layer regulates moisture, temperature, and nutrient regimes. These variables obviously affect forest productivity. Soil temperature is one of the more easily observed changes. The trend is for a gradual reduction in soil temperature as succession progresses. During the white spruce stage when the forest floor is well developed, permafrost may begin to develop. The black spruce stands on old river terraces have well-developed permafrost layers.

CONSIDERATIONS FOR REGENERATION OF WHITE SPRUCE

Two broad categories of management practice must be considered for regenerating white spruce on floodplain sites.

1. Practices needed to regenerate white spruce following harvest on sites currently supporting white spruce — the only forests that have commercial value at the present time. Examples of forest types that might require these practices are *Picea glauca/Alnus* spp./*Hylocomium*, *Picea glauca*/feathermoss, *Picea glauca/Alnus* spp./*Vaccinium/Hylocomium*, *Picea glauca/Alnus/Ledum*/feathermoss, and, possibly, *Populus balsamifera-Picea glauca/Alnus/Equisetum* (classification follows Viereck and Dyrness 1980). Practices would be those normally associated with white spruce regeneration (e.g., clearcutting, followed by site preparation and natural or artificial regeneration, or a shelterwood system, followed by site preparation and natural regeneration).
2. Practices that promote or encourage optimum regeneration and early development of white spruce during the initial stages of forest development. Vegetation types requiring these practices (e.g. underplanting or artificial seeding) might include *Populus balsamifera/Alnus tenuifolia, Populus balsamifera/Salix-Alnus*/herb, and, perhaps, *Salix-Alnus incana/Equisetum*. The rationale behind these practices is that natural regeneration of white spruce is not always adequate in these vegetation types. The objective would be to bring white spruce stocking to a level that would ensure well-stocked stands as white spruce became dominant during the normal course of succession.

Some cultural practices may be generally appropriate to both these situations, although site conditions may differ considerably. For example, site preparation may be necessary in both situations, but the nature of the forest floor may require different methods to obtain the necessary microsite conditions. There may also be differences in overstory conditions, litter fall, moisture regime, and other variables.

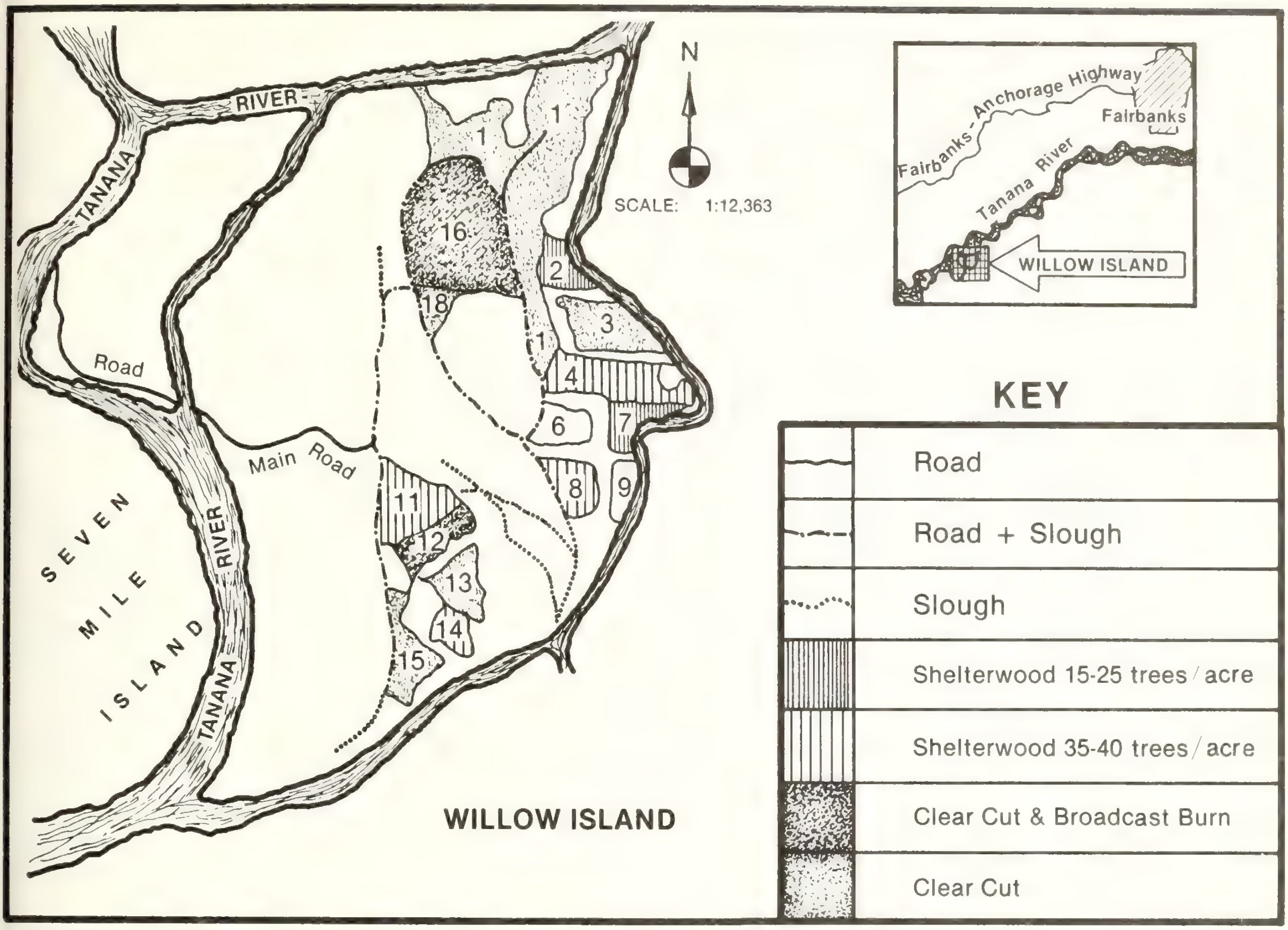

Figure 1.–Location of Willow Island and cutting units. Units 11 to 15 are in the open white spruce/alder/*Hylocomium* type; soil is the deep phase of the Salchaket series. Unit 16 and the part of Unit 1 just north of 16 are in the open white spruce/ alder/*Vaccinium*/ *Hylocomium* type and the woodland white spruce/*Ledum*/*Vaccinium*/feathermoss type; soils for both are in the Tanana series. The remainder of Unit 1 and Units 2-9 are in the open white spruce/alder/*Vaccinium*/*Hylocomium* type; soil series for this area is Salchaket intermittent frost phase.

Table 1– Stand type and soil characteristics for seven white spruce stands on Willow Island

Stand Type[1]	Stand[2]	Soil[1]	Organic layer depth[1]	Permafrost[2]	Age Range[2]	Height of dominants[2]
			(cm)		(years)	(m)
Woodland white spruce/ *Ledum*/feathermoss	1	Tanana	15-25	Present	131-250	17
Open white spruce/alder/ *Vaccinium*/*Hylocomium*	3	Salchaket[3]	10-23	Present[3]	208-326	32
	4	Salchaket[3]		Present[3]	77-370	28
	6	Salchaket[3]		Present[3]	99-380	38
Open white spruce/ alder/*Hylocomium*	2	Salchaket[4]	10-15	Absent	151-243	33
	5	Salchaket[4]		Absent	91-116	29
Closed white spruce/ alder/*Hylocomium*	7	Salchaket[4]		Absent	95-130	29

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[1] C.T. Dyrness, Institute of Northern Forestry, U.S. Department of Agriculture, Forest Service, Fairbanks, AK. Unpublished data.

[2] As assigned in Juday and Zasada (1984).

[3] Frost described as frost phase of Salchaket soil, much more variable than in Tanana soil.

[4] Deep phase of Salchaket soil.

Regardless of the management practices considered, the question of site stability and longevity must be addressed. Will a given site still be present when the forest crop is ready for harvest? Even though higher terrace elevations make white spruce sites seem relatively more stable than younger sites, they do erode. At present, there is no method of predicting site stability over the length of a white spruce rotation. Examination of old aerial photographs, observation of current rates of bank erosion, distance from main channel, and other variables can help predict stability, but nothing can provide an absolute answer.

The remainder of this paper will consider only regeneration following harvesting of white spruce, although practices that promote optimum regeneraton during early forest development are no less important. Walker[2] is studying the establishment of white spruce and other species in a number of successional stages on the Tanana River floodplain. His study should provide information on which to base management alternatives and to design additional studies to provide practical answers.

Regeneraton of white spruce following harvesting is currently being studied on Willow Island. This island, located near Fairbanks, Alaska, is on the Tanana River floodplain. The Willow Island study was developed to examine regeneraton of white spruce under several combinations of silvicultural systems (shelterwood, clearcut) and methods of site preparation (burning, mechanical) (fig. 1), as well as to provide some insight into the effects of harvesting on white spruce ecosystems.

Willow Island covers approximately 250 hectares, and at least 90 percent of the island was covered by white spruce stands. Topographic relief is about 2 meters. The lowest areas are the bottoms of old river channels (Juday and Zasada 1984). Dyrness[3] identified four major white spruce stand types and two soil types (table 1). Juday and Zasada (1984) further characterized stands in each of the types identified by Dyrness (table 1).

We treat Willow Island as one unit of land at present. However, formation of the island was a complex process that has taken several hundred years, and the island continues to change (Juday and Zasada 1984). The channels on the east and south sides carry water only at high river stages. The channel to the north carries water at all stages but becomes very shallow at low stages. The channel on the west is the most significant and, although not the main channel of the river, appears to be an important secondary channel. There are many old channels on the island (fig. 1) that carry water only at flood stage.

Site classification, as discussed elsewhere in this workshop, can be used to identify appropriate management alternatives. Some initial observations on Willow Island that have implications for land managers follow:

1. Height-growth patterns of dominant trees in the seven stands identified by forest and soil type in table 1 appear to be quite different (fig. 2). One can only speculate whether these differences will continue following logging or whether the regeneraton growth will be similar to early stand development of first-generation white spruce (see curve for stand 5, fig. 1). The stands with the slowest height growth are those growing on the deepest organic layers and coldest soils. Removal of the overstory and disturbance of the organic layers will certainly affect soil temperatures and decomposition rates, and these will affect forest growth and development.

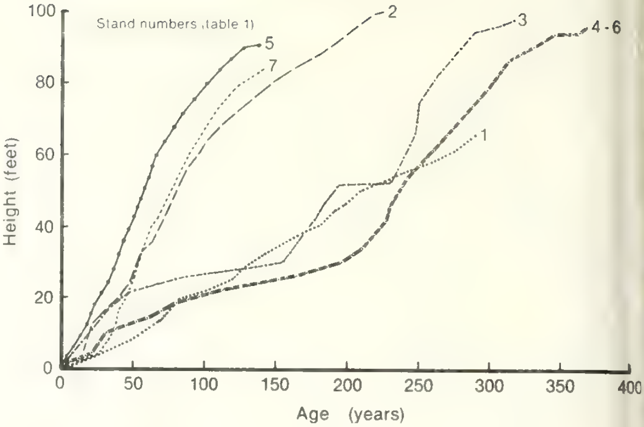

Figure 2.–Height-growth patterns of dominant white spruce growing in seven stand types. See Table 1 for soil characteristics in these stands.

2. Different treatments and/or equipment may be needed for some stand types. For example, site preparation with a patch scarifier and rubber-tired skidder was easier and appeared to be more effective on the better drained, open *Picea glauca/Alnus/ Hylocomium* types than on the open *Picea glauca/Alnus/ Vaccinium/Hylocomium* types. Poorly drained surface soil conditions, due in part to a shallow active layer (i.e., permafrost close to surface), caused the skidder to bog down, and patches made by the scarifier filled with water. This was not a problem on the well-drained sites. This observation suggests that nonmechanical site preparation (e.g. prescribed burning) may be more effective on the wet sites, or that mechanical scarification should be delayed until frost levels are deeper and the surface soil is better drained.
3. Some portions of the *Picea glauca/Alnus/Hylocomium* type have been flooded, and silt deposition has temporarily covered the moss/organic layers, essentially converting this type to a *Picea glauca/Alnus* type. This can be an important distinction because undisturbed *Picea glauca/Alnus* stands can have abundant regeneration, while in *Picea glauca/Alnus/ Hylocomium* stands regeneration is scattered and not abundant. The portion of the *Picea glauca/Alnus/Hylocomium* type affected by this flooding/siltation process is usually confined to a narrow band adjacent to the river. However, I have observed abundant regeneration in natural stands resulting from this process up to 300 feet from the active river channel. Zufelt[4] has observed abundant regeneration of white spruce following logging on silt layers deposited by flooding. These observations substantiate the belief that recognizing distinctions such as these could be important to regeneration planning.

Other differences between site types will certainly become evident as vegetation develops and the study progresses. There is little doubt that some level of vegetation or site classification must have both soil and vegetation components to be useful in silviculture planning.

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[2] Lawrence R. Walker, Institute of Arctic Biology, University of Alaska, Fairbanks, AK, personal communication.

[3] C.T. Dyrness, Project Leader, Institute of Northern Forestry, USDA Forest Service, Fairbanks, AK, personal communication.

[4] W.J. Zufelt, Tanana Chiefs Conference, Fairbanks, AK, personal communication.

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ECOLOGICAL CLASSIFICATION OF ALBERTA FORESTS AND ITS APPLICATION FOR FOREST MANAGEMENT

Ian G.W. Corns and Richard M. Annas

ABSTRACT: A forest-ecosystem classification for a 4.6 x 10^6-ha west-central Alberta study area was designed using several available sources of vegetation, soil, and forest-productivity information. Management interpretations using available ecological classification and reconnaissance soil-survey information were made for the following management concerns: harvest season and method; site-preparation intensity; soil-compaction, puddling, and erosion hazards; reforestation species, method, limitation, frost-heave hazard, and seedling-transplant mortality; site productivity; fire hazard; vegetation-competition hazard (type and severity); windthrow hazard; rodent-damage hazard; and common soil map units for each of twenty-five ecosystem associations.

INTRODUCTION

In recent years a greater appreciation of the value of forested land by a variety of potential users has intensified interest in ecosystem classification, evaluation of variation in forest site productivity, and in inventories of rapidly changing landscapes. Early forest-site research in the boreal forest of Alberta, Saskatchewan, and Manitoba has fallen behind other parts of Canada and the United States mainly because only recently (the last 25 years in Alberta) has any real utilization demand been put upon that forest region. The growing concern that forest resources are being depleted too rapidly or are being managed in a suboptimal manner is prompting the search for means to utilize most effectively the forest resource while maintaining its productivity.

Some of the earliest work in the western boreal forest was done in Alberta by Brinkman (1931, 1936) using lichens and mosses as site indicators. Smithers (1956) assessed site productivity in dense lodgepole pine stands in the Kananaskis Forest Experiment station, Alberta. Duffy (1964) used multiple-regression techniques to find relationships between site factors and growth of lodgepole pine in the Alberta foothills. Duffy (1965) developed a forest-land classification for the Mixedwood Section of central Alberta on the basis of differences in soil parent material and soil-moisture status as they influence white spruce site index. Dumanski et al. (1973) evaluated the productivity of lodgepole pine forests using soil-survey maps for the Hinton-Edson area. Lesko and Lindsay (1973) related lodgepole pine and white spruce site index within fifteen forest types to soils in the Chip Lake map area in westcentral Alberta. In addition, several descriptions of vegetation distribution in northern and northwestern Alberta have been made by Lewis et al. (1928), Dowding (1929), Raup (1933, 1934, 1946), Moss (1953, 1955), Moss and Pegg (1963), LaRoi (1967), Achuff and LaRoi (1977), Corns (1978), and, most recently, by Krumlik et al. (1978) during a biogeoclimatic classification of Alberta's forests and also during a biogeoclimatic classification of the British Columbia Forest Products Forest Management Agreement Area (Krumlik et al. 1982). Comprehensive reconnaissance soil surveys and interpretations for the study area have been made by Dumanski et al. (1972), Twardy and Corns (1980), and Knapik (1983).

The objectives of the present study were to classify and describe ecological zones (ecozones) and their component forest ecosystems within the study area with respect to their floristic composition, environmental characteristics, successional relationships, and potential for fiber production, and to make interpretations for forest management. All available, relevant sources of vegetation, soils, and climate information were consulted and, if possible, incorporated into the present classification and interpretations.

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The classification is a hierarchical system that corresponds to he biogeoclimatic system developed in British Columbia by Krajina (1965) and students; it also parallels the scheme used by the Canadian Committee on Ecological Land Classification (CCELC). The system used in western Alberta uses four fundamental classification levels: ecozone, subzone, ecosystem association, and ecosystem-association phase. The ecozone corresponds to the biogeoclimatic subzone as used in British Columbia (Krajina 1965, Pojar 1983), the ecoregion of Strong and Leggatt (1980), and the forest section of Rowe (1972). The ecozone defines a geographic area that is controlled by the same regional climate (macroclimate) and by characteristic zonal soils and vegetation that have developed in response to climate. The subzone, a subdivision of the ecozone, is similarly controlled by macroclimate, but it exhibits less variability in soils and vegetation. Ecosystems at the level of the biogeocoenose of Sukachev and Dylis (1964) are grouped into ecosystem associations which resemble the plant association of Braun-Blanquet (1928) and the habitat type of Daubenmire (1952). Ecosystem-association phases are not a taxonomic category in the ecosystem-classification system but are recognized in order to facilitate more precise resource-management interpretations. Phases of an ecosystem association are distinguished on the basis of differences in physiographic features (slope per cent, slope position, aspect, etc.) soil properties (i.e. texture), parent materials, and bedrock geology (Mitchell and Green 1981). Ecosystem associations and phases are considered to be the most-practical operational units and all management considerations are evaluated at this level.

STUDY AREA

Location and Extent

The study area is located in west-central Alberta between latitudes 53° - 55° N and longitudes 116° - 120° W. The area includes four National Topographic Series map sheets: Wapiti (83L), Iosegun (83K), Hinton-Edson (83F), and part of Mount Robson (83E, fig. 1) comprising an area of approximately 4.6 x 10^6 ha.

Physiography, Geology, and Soils

The predominant physiographic regions in the study area are in the Alberta Plateau (Bostock 1970) and the Rocky Mountain Foothills. The area is underlain primarily by the Paskapoo Formation of Paleocene to Late Cretaceous age and consists of weakly consolidated beds of shale, sandstone, coal, and chert conglomerate.

Both Cordilleran and Keewatin (Continental) glacial ice-covered parts of the study area. The influence of the Cordilleran ice was restricted to the south and west and affected over one-third of the study area. The remainder of the area was covered by the Keewatin ice sheet in at least two ice advances. Surficial deposits include glacial till of Keewatin and Cordilleran origin occurring as ground moraine, glaciolacustrine silts and clays with bedding, glaciofluvial coarse gravels occurring as river terraces, aeolian sands, recent alluvial deposits, and organic peat. A few small areas of shale, sandstone, coal, and conglomerate outcrops are present in the more mountainous areas in the southwestern portion of the map area. Elevations range from 600 to 2450 m ASL.

Soils of the Luvisolic, Brunisolic, Gleysolic, Regosolic, Podzolic, and Organic orders of the Canadian soil classification system (Canada Soil Survey Committee 1978) are represented in the study area. The dominant soil subgroups are Orthic Gray Luvisols, Brunisolic Gray Luvisols, Gleyed Gray Luvisols, Podzolic Gray Luvisols, and Orthic Eutric Brunisols (Boralfs, Aqualfs, Atalfs, Cryochrepts, and Eutrochrepts. (Soil Survey Staff 1975).

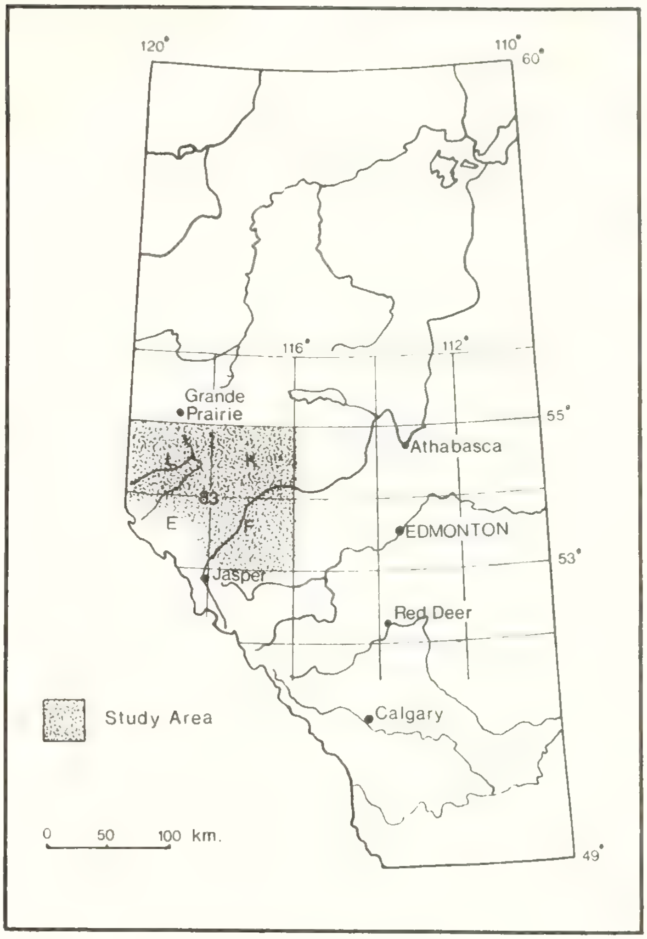

Figure 1.--Location of the Alberta study area.

More detailed descriptions of the nature and extent of the soils in this area are discussed by Knapik (1983), Twardy and Corns (1980), and Dumanski et al. (1972). These reports are accompanied by 1:126,720 scale maps.

Climate

Köppen's classification of climate describes the study area as a cold snow forest (Stringer 1972). This climate is characterized by cool summers and cold winters. The May 1 to September 30 period has a mean air temperature of 10-11°C, an average precipitation of 38-46 cm, 25-50 per cent of which falls as snow between November and March, a potential evapotranspiration of 38-43 cm, and a frost-free period (greater than 0°C) of 60 to 160 days (MacIver et al. 1972). Mean January air temperature (mean of daily max. and min.) at Edson is -14.0°C. Grande Prairie to the north of the study area is colder (-17.3°C), and mean monthly air temperatures are below freezing for all stations between November and March inclusive (Environment Canada 1975).

Vegetation

Most of the forest vegetation of the study area lies within the Mixedwood (B 18a), Lower Foothills (B 19a), and Upper

Table 1--Examples of management interpretations from ecosystem classification

							Reforestation interpretations				
Ecosystem association	Season[1]	Method[2]	Site preparation intensity[3]	Soil compaction hazard	Soil puddling hazard	Soil erosion hazard	Species[4]	Method	Limitations	Frost heave hazard	Seedling transplant mortality
Lower Boreal Subzone:											
Picea glauca/Equisetum arvense/Hylocomium splendens	W	CC PC	H	H	M-H	M-H	wS	Bare-root	Excess moisture	H	H
Populus tremuloides/ Vibernum edule/Aralia nudicaulis	S	CC	M-H	H	M-H	H	A, wS, lP	Bare-root, container	Excess moisture, fine texture	M-H	M
Pinus contorta/Elymus innovatus	S	CC	L	L	L-M	L-M	lP, A	Natural seed, container	Drought	L	M
Upper Boreal Subzone:											
Pinus contorta/Alnus crispa/Cornus	S	CC	L-M	M	L-M	L-M	lP wS	Container, natural seed	Competition	M	L-M
Pinus contorta-Picea mariana/Ledum groenlandicum/ Pleurozium schreberi	S	CC	L-M	M-H	M-H	M-H	lP	Container, natural seed	Excess moisture on some sites	M	L-M
Pinus contorta/ Vaccinium myrtilloides/ Cladonia spp.	S	CC	L	L	L	L	lP	Container, natural seed	Drought	L	M
Subalpine Zone:											
Pinus contorta/ Rhododendron albiflorum/ Rubus pedatus	W	CC	L-M	M	M-H	M-H	lP	Container	Excess moisture in spring	M-H	M

[1] Season: W - winter; S - summer
[2] Method: CC - clearcut; PC - patch cut; SC - selective cut
[3] Site Preparation intensity and others: H - high; M - medium; L - low
[4] Species: wS - white spruce; lP - lodgepole pine; A - aspen; bS - black spruce

Foothills (B 19c) sections of the Boreal Forest Region plus a small area within the East Slope Rockies Section (SA 1) of the Subalpine Forest Region (Rowe 1972). These units correspond to the Boreal Mixedwood, Boreal Foothills, Boreal Uplands, and Subalpine Ecoregions mapped at 1:1,500,000 for Alberta by Strong and Leggat (1981).

METHODS

Plot Sampling and Classification

Data were obtained from approximately 900 sample plots from the following studies: Krumlik et al. (1978, 1979, 1982), Nemeth et al. (1981), Corns (1978), and Lesko and Lindsay (1973). Although the work of Lesko and Lindsay (1973) is from the Chip Lake map area adjacent to the southwest corner of the study area, it is relevant to much of the lower elevations of the study area farther north. The 0.01 to 0.04-ha sample plots were selected using forest-cover maps and aerial photographs within well-developed homogeneous forest stands on a variety of soils and landforms. In all the studies the sample plots were placed subjectively to best represent soil and vegetation conditions. Plot location and general physiography (elevation, slope gradient and aspect, topographic position, relief shape, and landform) were recorded on field sheets. Soils were described according to the Canadian System of Soil Classification (Canada Soil Survey Committee 1973-1978). Vegetation was sampled in a fashion compatible with Braun-Blanquets' (1932) methods or those described by Walmsley et al. (1980). Classification was done by tabular comparison (Mueller-Dombois 1974) using computer-generated vegetation and environment tables. Additionally, all sample plots included forest mensurational data. Site index was determined for all plots based on dominant and codominant trees, and for most plots stand volumes and mean annual increment in total volume (MAI) were also determined.

Interpretations for Forest Management

Interpretations for forest management (table 1) are made within an ecosystem association framework and are based upon a variety of information sources including reconnaissance soil-survey reports, available forest ecological information, and observations by operational foresters and the authors. Quantitative data were not available for many interpretations nor for some ecosystem associations. In these instances, data from similar environmental/ecological situations were extrapolated. Interpretations were made for a variety of attributes significant for forest management: season and method of harvest, site-preparation intensity, soil-compaction hazard; soil-pud-

Table 1--continued

Ecosystem association	Species	Productivity X MAI	Productivity Site index (70)	Fire hazard[5]	Vegetational type	Competition severity	Windthrow hazard	Rodent damage hazard	Common soil map units
Lower Boreal Subzone:		(m^3/ha/yr)	(m)						
Picea glauca/Equisetum arvense/Hylocomium splendens	wS	3.7	11.8	$\frac{\text{M-L M-L}}{\text{M-L M-L}}$	Reedgrass, sedge	M-H	H	M	SIP, SKY, GUN
Populus tremuloides/ Vibernum edule/Aralia nudicaulis	A	4.3	19.8	$\frac{\text{L-M L-M}}{\text{H L-M}}$	Reedgrass, forbs, willow	M-H	M	H	LDG, DON
Pinus contorta/Elymus innovatus	lP	3.4	16.0	$\frac{\text{M-H M-H}}{\text{H M-H}}$	Ryegrass	L	L	L	RBB
Upper Boreal Subzone:									
Pinus contorta/Alnus crispa/Cornus canadensis	lP	4.0	17.6	$\frac{\text{M-L M-L}}{\text{H M-L}}$	Alder, reedgrass	M	L	H	EDS, MLB TOR
Pinus contorta-Picea mariana/Ledum groenlandicum/ Pleurozium schreberi	lP	3.8	15.8	$\frac{\text{M-L M-L}}{\text{H M-L}}$	Reedgrass	L-M	M	M	EDS, SIP, TOR, COP
Pinus contorta/ Vaccinium myrtilloides/ Cladonia spp.	lP	1.3	11.9	$\frac{\text{L-M L-M}}{\text{H L-M}}$	Ryegrass	L	L	L	BKM
Subalpine Zone:									
Pinus contorta/ Rhododendron/albiflorum/ Rubus pedatus	lP	3.0	13.1	$\frac{\text{M-H M-H}}{\text{H M-H}}$	Reedgrass, Rhododendron	L	M	L	RBB, COP

[5] Fire hazard: $\frac{\text{cured dormant crown (early spring, late fall) active growth crown (late spring to early fall)}}{\text{cured dormant surface (early spring, late fall) active growth surface (late spring to early fall)}}$

Table 2--Optimum season of harvest

Season	Internal drainage	Texture B Horizon	Soil map unit
Winter only	Imperfectly to very poorly	CL-HC	DON1; SIP1, 2; EDS2; 2,3,4
Summer or winter	Rapidly to moderately well	S-CL	

dling hazard; soil-erosion hazard; reforestation method, limitations, preferred species, seedling frost-heave hazard, and anticipated seedling mortality; productivity in site index and MAI for dominant species; fire hazard; vegetational competition (type and severity); windthrow hazard; and snowshoe hare-damage hazard. Summary tables used in making interpretive evaluations are included in the following section.

RESULTS AND DISCUSSION

Ecosystem Classification

To date twenty-five ecosystem associations have been described for the west-central Alberta study area. The descriptions of these are the subject of another manuscript in preparation.

Management Interpretations

Management interpretations were made of nineteen forest management concerns using the ecological classification and reconnaissance soil surveys for the study area (table 1). A discussion of these follows.

Timber Harvest.–

A. Season: The recommended season of harvest (table 2) is designated as winter (W) when ground is frozen or summer (S) depending largely upon the wetness of the site and its ability to support heavy equipment without site degradation. Sites suitable for summer harvest are generally also suited for winter operations. All sites should be avoided during spring snow melt, when soil moisture is above field capacity.
B. Method: The harvest method includes both the method of falling the timber and the means of removing the fallen logs from where they were fallen.

Table 3--Logging method

Method	Tree cover
Large clearcut	Lodgepole pine, mixed pine, and spruce
Patch or strip cut	Even-aged spruce
Selective cut	Uneven-aged spruce

i. Logging Method (table 3) — Clearcutting (CC) generally proved to be a satisfactory method of harvest on a wide variety of forest sites in Alberta, particularly those cut for lodgepole pine pulpwood. Small (e.g. <20 ha) patch cuts (PC) are desirable in even-age spruce-dominated stands to facilitate spruce natural regeneration. In old growth and uneven aged spruce, selective cutting (SC) may be appropriate so that old trees are removed and younger trees are preserved and released as well as providing seed for natural regeneration. There are other methods and modifications available (e.g., seed tree, shelterwood) but these presently appear not well suited for most Alberta conditions, especially from an economic point of view.
ii. Log removal — The widely used rubber-tired skidders are satisfactory for most sites, although low ground-pressure track skidders (e.g., FMC) will minimize soil disturbance, compaction, and erosion on wet, fine-textured soils logged when the ground is not frozen. Heavy equipment such as feller-bunchers should be restricted to well drained, coarse-textured soils to minimize compaction or should be used during winter when soils are frozen.

Site-preparation intensity.--Site-preparation intensity recommendations (table 4) were made as low, medium, or high depending upon the environment (including soil properties), vegetation-competition hazard, and seed supply. Several options may be available to accomplish similar results. These are discussed below:

Low intensity: These sites are generally moderately well to rapidly drained, have shallow (>10 cm) soil organic layers, minimal plant-competition problems, and low to moderate slash abundance. Satisfactory lodgepole pine regeneration may be achieved on many sites with a good cone supply without site-preparation if the slash and cone are well distributed. Methods of low-intensity site preparation include the following:
a. Screefing (mattock, boot, spade). This may be appropriate when planting bare-root stock on topographically irregular sites, sites inaccessible to large machinery, sites where soil compaction may be a problem, and sites where plant competition, especially reedgrass (*Calamagrostis canadensis*), is well established and where more-severe site preparation may further stimulate competition.
b. Anchor-chain drags. This method gives satisfactory results on a wide variety of sites and scarification intensity and degree of coverage can be regulated by the number and length of the drags. Caution should be taken to minimize soil compaction on sites with fine soil texture or weak structure.
c. Toothed scarifier blade. The main concern should be to redistribute slash (cones) if necessary as the shallow organic layer should not pose a significant impediment to rooting seedlings. Soil compaction may be significant on fine-textured soils or on those with weak structure.

Moderate Intensity: These sites are moderately well to imperfectly drained, have moderately deep (10-15 cm) soil organic layers, moderate to high plant-competition ratings and low to moderate slash abundance. Methods of moderate-intensity site preparation include the following:

a. Shark-fin barrels. This equipment does a satisfactory job on level to gently sloping moist sites with moderate slash abundance and moderately deep organic layers. Degree of scarification can be regulated by the amount of fluid put in the drums as well as number and length of the attached anchor-chain drags.
b. Toothed scarifier blade. This equipment on a large tractor (e.g., Caterpillar D6 and larger) is capable of spreading large amounts of slash and penetrating deep organic layers.
c. Bracke scarifier. This machine can provide good results on wet sites or where plant competition is a problem and can provide planting sites with a wide range of moisture regimes.

High Intensity: These sites are poorly to imperfectly drained, with deep (15-30 cm) organic horizons, generally high plant-competition ratings and low to high slash abundance. Methods of severe-intensity site preparation include the following.

a. Martinni plow. This rear-mounted plow is capable of exposing mineral soil on wet sites with deep organic layers. Its relatively large size and weight make it more difficult to maneuver and increase the chances of getting stuck with resulting soil damage compared with alternative equipment. Chances of subsoil glazing and compaction are greater with the Martinni plow than with some other "severe" methods (e.g., the ripper plow). Flooding of the furrow is a problem on very wet sites. Furrows should run parallel to slope contours to minimize soil erosion particularly during spring runoff and on fine-textured till and lacustrine materials. On very gentle, short slopes on less erodible materials (e.g., some tills), downslope orientation of the furrows could provide some drainage, with minimal erosion.
b. Ripper plow (Craig - Simpson, C & S). This plow and adaptations of it have proved to be versatile machines for site preparation on wet sites, requiring less energy than the larger Martinni and creating less disturbance of the site. The ripper plow is often used in conjunction with a brush rake or toothed scarifier blade to move heavy slash, particularly the presently unutilized hardwoods, into windrows.

Table 4--Site-preparation intensity

Intensity	Internal drainage	Vegetational competition	Slash abundance	Organic layer thickness	Soil map unit
				(cm)	
Low	Rapid to moderately well	Low	Low to moderate	< 10	COP1; SHP1,2; EDS1,2,3,4
Moderate	Moderately well to imperfectly	Moderate to high	Low to moderate	10-15	COP3; DON1 JUY1,2
High	Imperfectly to very poorly	High	Low to high	15-30	GUN1; KN2; SFP1,2

Table 5--Soil compaction hazard[1] (use chart from left to right)

Texture	Coarse fragments	L + F thickness	Structure	Character of coarse fragments	Soil map unit	Rating
	(%)	(cm)				
L,SiL, SiCL, CL, Si, heavy SL, vfSL	<35	<5	Strong	All	DON1; SIP1,2	Moderate
			Mod. & weak	All	EDS1; RBB7	Severe
		>5	Mod. & weak	All		
			Strong	All	RBB6; SHP1	Moderate
	35-60	<5	Mod. & weak	Rounded		
				Angular	SMT1; MBN4	Low
			Strong	All		
		>5	Mod. & weak	Angular		
				Rounded	ERR3; STT	Moderate
			Strong	All	COP1; CAW	Low
	>60	any	All	All		
LS,S	any	any	All	All		
SiC, C, SC, SCL	>35	any	All	All		
	<35	<5	Strong	All		
			Mod. & weak	All	COP3; BKM6	Moderate
		>5	Mod. & weak	All		
			Strong	All	ESH; LDM1	Low

[1] In making a rating, consider the characteristics of the litter and upper 30 cm of mineral horizon(s). A wet or moist condition is assumed. The horizon which gives the poorest rating is used. Table adapted from Boyer (1979).

c. Brush rake. This multitoothed bulldozer blade can effectively increase the receptive area for regeneration by putting heavy slash and unutilized hardwoods into windrows and by removing excess organic matter from the soil surface. As with other treatments that involve use of heavy equipment, soil compaction is likely to result.

d. Cazes and Heppner plow (C & H). This wide, front-mounted V-blade can effectively remove virtually all vegetational competition (including well-established trees) plus soil-organic and surface-mineral horizons. The resulting denuded surface can be very susceptible to erosion on slopes, especially where soils are fine textured. Soil compaction and glazing of the subsoil could also be anticipated on fine-textured soils. The edges of the bladed strips are usually the best sites for planting. In these situations, organic matter and nutrients are likely to be more abundant, and susceptibility to drought and frost heave is likely to be less. It is believed that less-severe scarification methods are probably adequate as preparation for planting on most sites and that the C & H plow should be restricted to areas of stable soils where stand conversion (e.g., aspen to lodgepole pine) is being attempted.

Soil interpretations.-- Soils interpretations for the various ecosystem associations are based upon the predominant soils found with each type. Reconnaissance soil surveys, completed over most of the study area, have rated soil-mapping units for a variety of relevant interpretations, including soil-erosion hazard, windthrow hazard, and transplant mortality. Work done by others (Boyer 1979, Townsend 1982) has enabled atings for soil compaction and puddling to be made for the predominant soils of each ecosystem type.

t must be recognized by the users of this manual that the atings are general and relative and that variation outside the atings in table 1 can be expected as the soils occurring with a given soil subgroup or map unit will have a range of properties. It is thus important to evaluate sites individually where site-specific information is desired. The ratings given in table 1 can be approximated by the operational forester by using the information and criteria provided below. The background information used to make the ratings comes from detailed sample-plot data plus relevant soil-survey reports (Twardy and Corns 1980, Dumanski et al. 1972, Twardy and Lindsay 1971, and Knapik 1983). Only relative ratings can be provided as quantitative data are scarce.

A. Soil compaction

The degree of soil compaction is influencd by a number of soil physical properties including texture, per cent coarse fragments, per cent organic matter, organic-layer thickness, structure, and the type of coarse fragments. Table 5 is adapted from Boyer (1979). Compaction reduces porosity and rate of water infiltration as well as increasing physical impedence to growing roots. The horizon which gives the poorest rating in the upper 30 cm of mineral soil will determine the rating for the soil. Most of the soils of the study area, particularly those of the Lower Boreal and Aspen-White Spruce zones are susceptible to compaction, moreso than those in the foothills within the Upper Boreal zone due to predominantly finer textures and fewer coarse fragments in the predominantly continental tills in the east.

Increased soil compaction has been shown to reduce forest productivity in many parts of the world. Quantitative data are not available for our area. Soil compaction can be minimized by keeping heavy machinery off the more susceptible soils when they are wet, by minimizing the area of logging roads or clearcuts, and by minimizing the number of passes over an area (Rothwell 1978). On susceptible soils, most compaction occurs during the first pass over the area by heavy equipment.

Table 6–Soil puddling hazard[1] (Use chart from left to right)

Texture	Coarse fragments	L + F thickness	Structure	Soil map unit	Rating
C, SiC, Si SiL, SiCL, SC, CL, vfSL	<35	⩽5	Strong	DON1; SIP1,2	Moderate
			Mod. & weak	EDS1; RBB7	High
		>5	Mod. & weak		
			Strong	RBB6; SHP1	Moderate
	35-60	⩽5	Mod. & weak		
			Strong	SMT1; MBN4	Low
		>5	Strong		
			Mod. & weak	ERR3; STT	Moderate
	>60	any	All	COP1; CAW	Low
LS, S	any	any	All		
L, SCL, SL	>35	any	All		
	<35	⩽5	Strong		
			Mod. & weak	COP3; BKM6	Moderate
		>5	Mod. & weak		
			Strong	ESH; LDM1	Low

[1] In making a rating, consider the characteristics of the litter, and upper 30cm of mineral horizon(s). A wet soil condition is assumed. The horizon which gives the poorest rating is used. Table adapted from Boyer (1979).

Table 7–Soil erosion hazard[1]

Hazard	Parent material	Texture B horizon	Slope %	Soil map unit
Low	Till	Medium to coarse[2]	<10	RBB1
	Colluvium, glaciofluval gravels, unconsolidated bedrock (sandstone, shale), organic	Variable	<5	JUY1, 2;STT
Moderate	Till	Fine to moderately fine	<10	EDS1,2,3
	Till	Medium to coarse	10-15	LDG 1,2,4,5,6,8
	Till	Very stony variable texture	16-60	MBN1,7
	Colluvium	Variable	5-30	ERR3
	Eolian	Coarse	0+	HRT1,3; HTN1 to 8
	Unconsolidated bedrock	Variable	5-9	COP1
	Organic	--	5-9	KNZ
High	Glaciolacustrine	Fine	0+	DON1
	Glaciofluvial	Medium to coarse	0+, especially Gleysols	GUN1
	Till	Fine to moderately fine	>10	EDS4; MBN4
	Till	Medium to coarse	>15	SHP1,2
	Colluvium	Variable	>30	
	Unconsolidated bedrock	Variable	>10	COP3
	Organic	--	>10	KNZ

[1] Ratings assume unvegetated surface. Dense vegetation cover will reduce hazard by at least one class.

[2] Textural groups are as follows: fine –sandy clay, silty clay, heavy clay; moderately fine—clay loam, sandy clay loam, silty clay loam; medium—very fine sandy loam, loam, silt loam, silt; moderately coarse—sandy loams; coarse—sands, loamy sand.

Compaction effects can be long lasting in the Pacific Northwest. Under some conditions, the surface few centimeters of compacted soil will recover within a few years to a few decades. The deeper soil compaction appears to require substantially more time, and the rate of this recovery is still largely unknown (Froelich 1982). Less is known of soil-compaction effects for the Canadian boreal forest, where repeated freeze-thaw cycles may be expected to help ameliorate compaction damage. Winter logging and site preparation minimizes compaction and the desirability of restricting summer operations to well-drained, coarse-textured soils is emphasized. Soil compaction effects are discussed further in reviews by Lull (1959) and Froelich (1973, 1982).

B. Soil Puddling

Puddling is the soil physical condition that results from the dispersal of soil particles causing destruction of the soil structure and the formation of a dense crust on the soil surface. This crust has the same effect as a thin compacted layer, and is most common on soil surfaces where litter has been removed by burning or by mechanical means. Reduced germination and increased mortality may be expected on soils compacted or puddled by logging equipment (Pritchett 1979). Wet, fine-textured soils with few coarse fragments, shallow organic layers, and weak structure are most susceptible to puddling, while soils of any texture with thicker organic layers, abundant coarse fragments, and strong structure are least susceptible (Boyer 1979, table 6). The ratings given in table 6 make the assumption that the organic layer is $<$ 5 cm. If the organic layer is $>$5 cm, a rating one class less severe (e.g., from moderate to low) would be applied.

C. Soil-Erosion Hazard

Soil losses from forested areas are normally very small. Increase in erosion and stream turbidity are due mainly to road construction and other activities that expose large areas of mineral soil (Pritchett 1979). There are many factors which influence the erodibility of soil and parent materials: texture, type of structure, degree of carbonate cementing (parent materials), stone content, amount and type of vegetation cover, slope angle, length of slope, occurrence of recent fire, rainfall intensity and seasonal distribution, and rapidity of snow-melt. Only water erosion is considered here. Wind erosion is generally not a problem in the study area with the possibile exception of some local soils in the Athabasca Valley southwest of Hinton. Infiltration capacity and structural stability are regarded as most important in controlling water erosion (Buckman and Brady 1960). Soil-erosion hazard is the expected rapidity and amount of soil loss due to wind and/or water that may be expected following removal of the protective vegetation cover in areas where the proper erosion-control measures are not implemented (Dumanski et al. 1972). Because of the many factors determining erodibility, generalized relative erodibility hazard ratings for soils under a plant association must be made assuming average rainfall intensity and rate of spring snowmelt using information published in reports by Dumanski et al. (1972), Twardy and Corns (1981), Knapik (1983) and Rutter (1968). Erosion will increase as slope steepens up to 80 per cent (40°); thereafter decreasing to zero as steepness approaches 200 per cent (90°) (Rutter 1968). Erosion will be greater on long slopes.

The relative erosion-hazard ratings described (table 7) are based primarily on soil texture, estimates of infiltration and permeability rates, soil structure, soil wetness, and slope angle, where surface organic layers have been removed.

a. Low – Parent materials (and soils developed on them) with a usually low erosion hazard include medium- to coarse-textured tills (slopes $<$10 per cent), colluvial materials (slopes $<$5 per cent), glaciofluvial gravels, unconsolidated bedrock (sandstones and shales; slopes $<$5 per cent), and organic soils (slope $<$5 per cent).

b. Moderate – Parent materials (and soils developed on them) with usually moderate erosion hazard include fine to moderately fine-textured tills (slopes $<$10 per cent), medium to coarse textured tills (slopes 10-15 per cent or up to 60 per cent if very stony), colluvial materials (slopes 5-30 per cent), aeolian deposits, unconsolidated bedrock (sandstones and shales; slopes 5-9 per cent), and organic materials (slopes 5-9 per cent).

c. High – Parent materials (and soils developed on them) with a usually high erosion hazard include glaciolacustrine deposits (any slope), glaciofluvial sands and silts (any slope – especially Gleysolic soils), fine- to moderately fine-textured tills (slopes $>$10 per cent), medium- to coarse-textured tills (slopes $<$15 per cent or steeper depending on stoniness), colluvial materials (slopes $>$30 per cent), unconsolidated bedrock (slopes $>$9 per cent), and organic materials (slopes $>$9 per cent).

Ratings of individual soil units mapped in the study area are available in reconnaissance soil surveys by Dumanski et al. (1972), Twardy and Corns (1980), and Knapik (1983).

Methods for minimizing erosion as a result of logging and road construction in Alberta are discussed by Rothwell (1978) and Lengellé (1976). A variety of practical "bioengineering" methods using vegetation as a means of stabilizing slopes and reducing erosion is discussed by Schiechtl (1980).

Reforestation Interpretations.--

A. Species selection

The species selected to reforest a site will depend upon both its biological and economic suitability. The latter is more difficult to judge since it is virtually impossible to know what forest products will be available to and desired by the consumer at the end of the rotation.

Clues to tree species biologically well adapted to a site can be determined from soil physical and chemical properties and the species (tree and understory) that occupy the site. Climate, soil-moisture regime, and to some extent nutrient regime can be inferred from the composition of the vegetation. Soil properties, particularly drainage and pH, will have a strong bearing upon the species selected for planting a site.

The current Alberta Forest Service Planning and Harvesting Ground Rules for Forest Management Area holders specify that tree regeneration on cut-over areas must average 1.8 to 2.5 m in height before adjacent trees can be removed in the second cut. This guideline appears to encourage reforestation using initially faster growing pine on sites that might be better suited to spruce production when the whole rotation period is considered. The rapid initial growth advantages of establishing pine rather than spruce may not result in the best economic yield or wildlife habitat in the long term.

The interpretations made for tree-species suitability consider only those species native to the study area and are based primarily upon the inferred ecological suitability of the site. Current markets for particular forest products have no bearing upon the interpretations The principal factors considered are climate, soil drainage, soil reaction (pH), organic-layer pro-

Table 8--Species selection for reforestation

Species	Elevation (m)	Drainage	pH	Organic thickness (cm)	Texture	Soil map unit
Aspen	<1100	Well to moderately well	5-7	<10	Heavy clay-loam	DON1; EDS1, 3
White spruce	600-1300	Well to imperfectly	4.5-7.5	<20	Heavy clay-loam	SIP1,2; ESH1; LDM1
Black spruce	600-1650	Well to poorly	3-6.5	10-30	Organic, heavy clay-sandy loam	KNZ; DVS1,2
Engelmann spruce	1300-1650	Well to imperfectly	4.5-7.5	<20	Clay loam-sandy loam	BKM3; ERR3; MSK4
Lodgepole pine	600-1650	Rapid to imperfectly	3-6	<10	Clay-loamy sand	EDS3; ERR1; HRT1,2,3,
Balsam fir	600-1300	Well to imperfectly	4.5-6.5	10-20	Heavy clay-sandy loam	BKM6; DON2; SIP1
Subalpine fir	1300-1650	Well to imperfectly	4.5-6.5	10-20	Heavy clay-sandy loam	BKM3; ERR3; MSK4,5

Table 9--Reforestation method on cutblocks[1]

Site conditions	Seed availability[2]	Species/reforestation options				Soil map uni
		Lodgepole pine	White spruce	Black spruce	Aspen	
Soil moderately well to rapidly drained, organic layer generally <10 cm, vegetation competition not usually a problem	Abundant	Natural	Natural	Natural	Natural root suckers	COP1,3 EDS1,2,3,4
	Sparse	Container, aerial seed[3]	Container, aerial seed	Container, aerial seed	Natural root suckers	
Soil imperfectly or more poorly drained, organic layer generally >10 cm, vegetation competition often a problem	Abundant	Container, bare root, natural	Container, bare root, natural	Container, natural	N/A	SIP1,2 ETH1,2,3
	Sparse	Bare root, container	Bare root, container	Container	N/A	

[1] This table should be used in conjunction with Table 8.

[2] Seed abundance is a function of slash and cone abundance plus proximity to adjacent seed-producing trees (especially important for spruce).

[3] Aerial seeding will have best results when 40-60% mineral soil is exposed and soil moisture is near field capacity.

perties (principally thickness), soil texture, and knowledge of tree growth on various sites. Table 8 presents the basis for species selection. Most of the soil information can be determined for the area in question from the reconnaissance soil survey reports and accompanying maps (Twardy and Corns 1980, Dumanski et al. 1972, and Knapik 1983). All factors should be considered together when rating a site in order to select the best-suited species. On sites that are environmentally suitable for more than one species, anticipated future markets may determine the selection.

B. Reforestation Method

Reforestation method here refers to the means by which satisfactory tree stocking is achieved on logged areas. The alternatives are natural seeding from slash or adjacent trees, root suckers (aspen), manual or aerial seeding, containerized planting stock, and bare root planting stock (table 9). The situations applicable to the various options are discussed below:

Natural: a. Pine -- Sites with good cone crops, soils that are moderately well or better drained, and organic layers less than 10 cm thick can generally be adequately restocked without additional planting. A light scarification might be necessary to distribute cones more evenly.
b. Spruce -- Satisfactory natural spruce stocking is likely to be attained only on sites with a continuing seed source such as on small patch or strip cuts or where seed trees are left. Spruce stocking on such sites will be favored where mineral soil is exposed and moisture is neither limited nor in excess.
c. Aspen -- Satisfactory natural aspen stocking is usually achieved by root suckering from cut trees without additional silvicultural input.
d. Balsam and subalpine fir -- These species generally acheive satisfactory natural regeneration only under the canopy of other trees.

Direct Seeding: Satisfactory stocking results from direct seeding can be expected only where there is a large amount of exposed mineral soils (40-60 per cent), minimal vegetational competition, and enough moisture to ensure germination and seedling establishment. Timing of the seeding operation is crucial.

Table 10–Frost heave hazard

Hazard	Internal drainage	Mineral soil exposure	Texture B horizon	Slope position	Soil map unit
		(%)			
Low	Rapidly to well	0-25	S-SL	Upper, crest	HRT1,2,3; BKM 1,4,6
Moderate	Moderately well	26-50	SCL-L	Mid	MBN1,4; RBB1
High	Imperfectly to poorly	>50	Si-SiC CL-HC	Lower, toe	DON1,2,3; SIP1,2

Table 11–Seedling transplant mortality[1]

Hazard	Soil reaction (pH)	Water-holding capacity	Organic-layer thickness	Moisture regime	Soil map unit
			(cm)		
Low	4.0-6.5	High	<10	mesic to permesic	DON1; EOS1,2,3,4
Moderate	6.6-7.0	Medium	11-15	subhygric	COP1,3; LDG1,2,3,4
High	>7.0	Low	>15	hygric to hydric subxeric to xeric	HRT1,2,3,4; HTN 1 to 8

[1] See Dumanski et al. 1972. This table should be used with Table 10.

Planting Containerized Stock: In general, seedling survival and early growth is proportional to the volume available for root growth and development. Consequently, a seedling grown in a unit such as a Spencer-Lemaire 55-cc container will generally outperform those in the standard 40-cc container, particularly on sites with potential vegetation competition or snowshoe hare-damage problems.

Bare-Root Stock: Bare-root planting stock can generally gain an advantage over containerized stock. This is especially so on sites with abundant vegetational competition because of the greater size and age of the bare-root stock. This is more true with white spruce than with pine, due to the slow initial growth of the spruce.

C. Limitations to Reforestation Success

The limitations discussed here are those of the site and do not include management considerations such as planting errors which can be just as significant as site limitations (Froning 1972). The limitations are self-explanatory and mainly include considerations such as excess moisture, drought, steep slopes, and vegetational competition. High soil reaction (pH) is a problem on some soils of ecosystem associations in the Athabasca Valley near Hinton. These are not described in this report.

D. Frost-Heave Hazard

Frost-heave hazard is rated for the predominant soils of the ecosystem associations described on the basis of their likelihood of heaving tree seedlings upon freezing (table 10). This rating is based primarily upon the texture of the surface soil horizons and upon the moisture content of the soil, reflected by its drainage class. The most susceptible soils are those with fine-textured surface horizons with high silt content and imperfect drainage and where surface organic layers have been removed. Topographic situation can be an important determinant of frost-heave susceptibility with depressional situations being most susceptible.

Table 12--Factors affecting fire-hazard rating

Environmental factors	Forest stand and vegetation factors
moisture regime	tree species present
soil drainage	crown diameter and depth
topography	flammability of understory species
prevailing wind direction	size distribution of fuels
climate	abundance of fuels, bark thickness, rooting depth, organic-layer thickness, stand density, abundance of lichen growth

E. Seedling-Transplant Mortality

Potential mortality of planted seedlings has been rated on the basis of the most prevalent soil types occurring with each ecosystem association (table 11). The ratings were based largely upon early survival of very young transplants in unprepared, natural soils in the Hinton-Edson area (Dumanski et al. 1972). Ecosystem associations' soils are rated as high in terms of seedling mortality if they exhibit abnormally high soil reaction (pH), if they have low water-holding capacities, or if they have thick organic-surface horizons and are excessively wet during the growing season (Dumanski et al. 1972).

Productivity of the ecosystem associations.--Average values of gross, mean, annual, total volume increment (MAI), and site index (70 yr) are given for the dominant species of each ecosystem association. The values are from sample plots in natural, unmanaged stands. Site index is primarily estimated using the curves by MacLeod and Blyth (1955), although data for 137 plots in the Wapiti map area are from stem analysis (Corns 1978).

Fire hazard.--Fire hazard is inferred from knowledge of the flammability of the component species of the ecosystem types and from observed fire behavior in various forest types. These ratings were assigned for "cured dormant state" (early spring and late fall) and "active growth state" (late spring to early fall) for both "crownfires" and "surface fires" with the help of the fire-research unit of the Northern Forest Research Centre, Edmonton. The subjective ratings (table 12) will be greatly influenced by weather, topography, and by local fuel loading.

Table 13--Vegetational competition hazard

Hazard	Internal drainage	Texture B hor.	Elevation	Soil map unit
			(m)	
Low	Well to rapidly	S-SL	>1200	HRT1,2,3; BKM 1,4,6
Moderate	Moderately well	L-SCL	1000-1200	COP1,2,3; MLB4,6
High	Imperfectly to very poorly	CL-HC; Si-SiC	<1000	LDM1,2; SIP1,2,3

Table 14--Windthrow hazard

Hazard	Internal drainage	Organic layer thickness	Exposure to strong wind	Soil map unit
		(cm)		
Low	Rapid to well	<10	Slight	BKM1,4,6; COP1,3
Moderate	Moderately well to imperfect	11-20	Moderate	DON1; MBM3; NMP1
High	Poorly to very poorly	21-30	Severe	SIT: SIP1,2,3; SKY1,2

Table 15--Hare and rodent damage hazard on regenerating cutblocks

Hazard	Abundance of, low dense woody vegetation	Slash abundance	Elevation	Soil map unit
	(%)		(m)	
Low	0-20	Low	>1200	
Moderate	21-40	Moderate	1100-1200	
High	>40	High	<1100	

Vegetational competition.--Vegetational competition is rated according to type (predominant species or species groups) and severity, with respect to its influence upon young tree seedlings (table 13). Competition occurs for light, nutrients, water, and space.

Types of vegetational competition include that by reedgrass (primarily *Calamagrostis canadensis*), sedge (*Carex* spp.), ryegrass (*Elymus innovatus*), green alder (*Alnus crispa*), willow (*Salix* spp.), bracted honeysuckle (*Lonicera involucrata*), and forbs (especially those with large amounts of biomass and dense roots/rhizomes including *Mertensia paniculata, Aralia nudicaulis, Aster conspicuus,* and *Epilobium angustifolium*). Within the study area, *Calamagrostis canadensis* is the most serious competitor with conifer seedlings. It can form a dense sod that can influence soil-moisture and nutrient regimes and rooting abilities of tree seedlings. Seedlings can also be greatly shaded by the dense grass cover and they can be pushed down by the grass when it is laid down by heavy snow, wind, or rain. *Calamagrostis* is most abundant on moist, fine-textured soils over a wide elevational range and appears to be most prevalent in the eastern portions of the study area. The other species mentioned also seem to be most competitive on moist, fine-textured soils at lower elevations. Thus the occurrence of a particular ecosystem association on such soils would result in a high rating for vegetation competition.

Windthrow hazard.--Windthrow-hazard ratings reflect characteristics of the predominant soils occurring as part of the ecosystem associations described (table 14). These characteristics affect the development of tree roots and, therefore, the risk of trees being blown over by normal winds. These ratings, termed low, moderate, and high, are estimated from knowledge of root development under varying soil conditions and from field observations (Twardy and Corns 1980). It appears that trees are most subject to windthrow on soils having thick organic-surface horizons that are affected by high water tables, or on lithic soils having thin soil over consolidated bedrock. Windthrow is most often a problem on Organic and Gleysolic soils. When rating specific sites, however, exposure and occurrence of winds of high velocity should be considered as additional factors. It was not possible to consider these latter factors in the present general rating.

Rodent-damage hazard.--The potential for seedling browsing by snowshoe hares and rodents (table 15) is dependent upon the presence of suitable habitat. Preferred habitat for snowshoe hares, the species causing most damage, is low, dense, woody vegetation (Buehler and Keith 1982, Keith 1966) and heavy slash that provides cover from predators as well as food. In the study area, such habitat is most plentiful in the Aspen-White Spruce zone and Lower Boreal subzone at elevations below 1100 m, particularly on moist sites. The hare and rodent damage hazard is based upon the presence of dense, shrubby understories in the ecosystem associations described. The ratings are relative and are given for near peaks in the population cycle in years of very high hare abundance. Other species groups responsible for girdling damage to young conifers include squirrel, mouse, vole, and porcupine.

CONCLUSIONS

A forest-ecosystem classification framework, used in conjunction with reconnaissance soil-survey information, appears to provide complementary bases for making forest-management interpretations. The classification framework has the potential for providing a basis for additional interpretations related to forest management, hydrology, wildlife management, recreation, etc. as well as for research.

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HOW TO CHOOSE SITE PREPARATION METHODS BASED ON SITE CLASSIFICATION

Per H. Stahl

Stand description or classification data can be most helpful in selecting suitable silvicultural treatments. This paper attempts to examine how they are used for selecting site preparation methods in Sweden.

Site preparation is necessary for good reforestation, except on the very most easily regenerated sites. It should provide the best possible environment for young plants to get established in. What characterizes this good environment varies from site to site and depends on soil characteristics, climate, etc. When specifying what is a good site preparation method this must therefore be qualified to a certain environment.

A good situation for plants to get established in is not necessarily the best for growing a maturing stand, so when choosing a site-preparation method, we must also consider its long-term effects on stand productivity. Site preparation must be site adapted.

I hope to be able to briefly describe a theoretic model, developed to help us select and develop site-preparation principles which combine the biological requirements for a good establishment with what is good for high sustained yield. After that I will describe a system which the Forest Service uses for choosing a site-preparation method. This system also considers some of the technical, environmental, and economic aspects of the choice.

The biological model has been developed by the Royal College of Forestry and the Logging Research Foundation. The purpose of the job was

- to judge, from a biological point of view, how suitable a number of different site-preparation principles are on different sites, and
- to determine how much of the forests, on mineral soils, should be site prepared according to the various principles.

The philosophy of the work, a joint evaluation of short- and long-term biological considerations, should be applicable on many occasions.

The basis for the analysis is a site-description system. In this, Sweden was divided into nine climatic zones, using regions (north or south of the "limes norrlandicus"), temperature sums, and the risk for early summer drought (fig. 1).

Within each of the nine zones, a number of different site types were defined using all possible combinations of

- soil-moisture class (dry, fresh, moist, wet)
- site-vegetation class (e.g. lichen, dwarf shrub, herb)
- humus-layer thickness
- soil texture.

All these data are available in our National Forestry Survey, and we can therefore determine how much land there is of the different types.

A number of different site-preparation principles are evaluated in the model, e.g. mineral-soil patch, mineral-soil strip, mineral-soil mound on humus, substantial ridge of mineral soil on a double layer of humus. These principles are more or less similar to what we can produce with today's methods. To widen the analysis, a number of other principles, for which we still have no technical solution, were defined, e.g. loosened up mineral soil or mixed humus and mineral soil.

The biological suitability of a certain site-preparation principle obviously depends on a number of factors, but the analysis only considers a few of the key factors. For the establishment, the two most critical factors seem to be the soil temperature and the water/oxygen relationship in the soil (i.e. the local drainage). The two critical factors for long-term productivity are nutrient release and the effect on the site's water balance (hydrology).

The method of analysis is summarized in figure 2.

1. Start the analysis by defining, for each site type, how the key factors should be influenced to make the site most suitable for establishing a new stand and as productive as possible.

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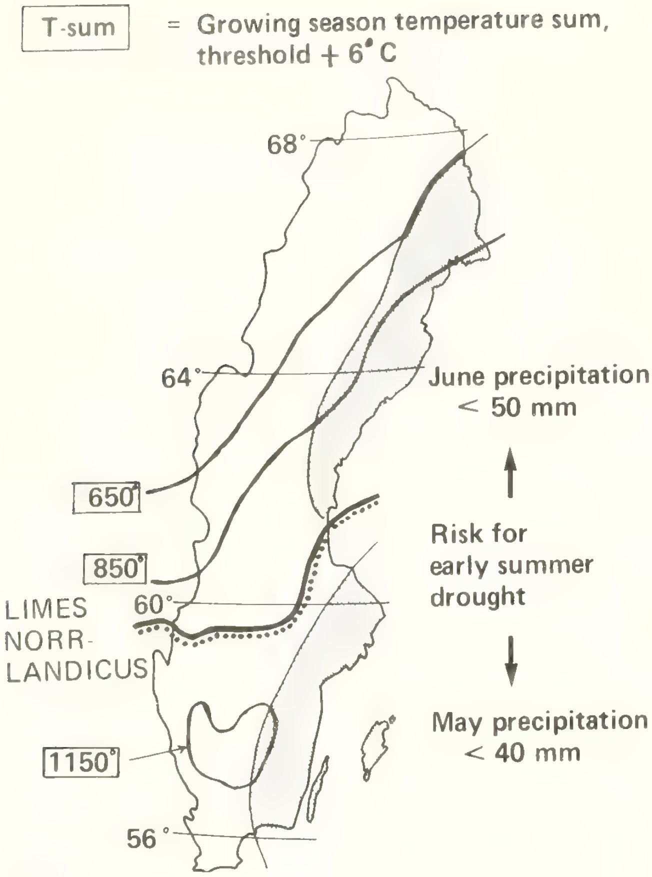
T-sum = Growing season temperature sum, threshold + 6° C
68°
64°
60°
56°
650°
850°
1150°
LIMES NORRLANDICUS
June precipitation < 50 mm
Risk for early summer drought
May precipitation < 40 mm

Figure 1.–Definitions for regions used in the model.

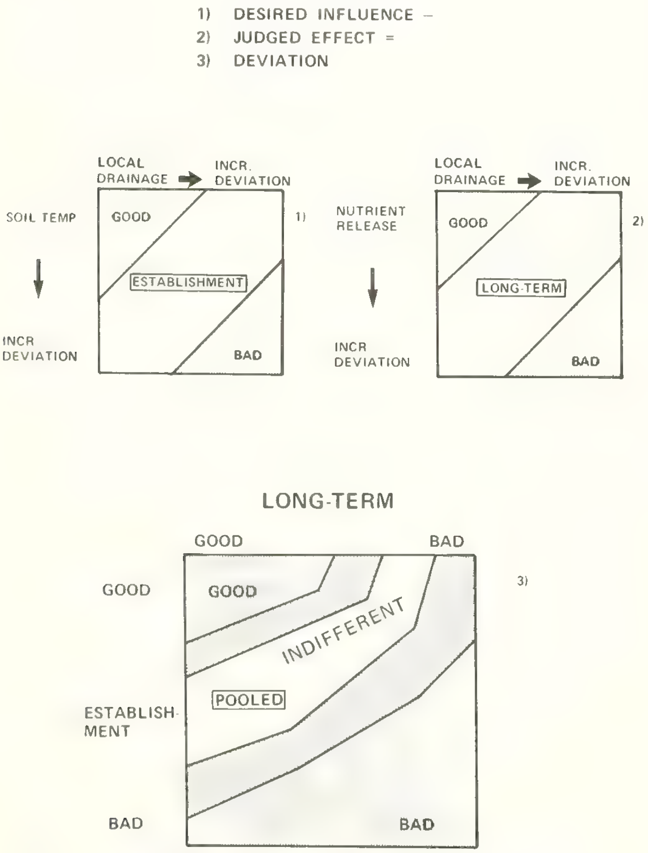

Figure 2.–Method of evaluation of site-preparation principles.

For example, on a cold and wet northern site with silty soils, one would certainly want to increase the soil temperature a lot and also get the planting spot well drained. The site may also need a strong cultivation, both to improve the water balance and to speed up the breakdown of the organic matter, i.e. to provide the stand with more available nutrients over a long period. On a dry southern site, with sandy soil, it would not be as important to increase the soil temperature, but it would be essential not to cause any loss of water. There is probably only a thin layer of humus on a site such as this, which should not be disturbed too much.

2. Then determine how each of the site-preparation principles will affect the four key factors on each site type.

A mineral-soil mound on a single or double layer of humus will, for instance, provide a warmer and better drained planting spot than a mineral-soil patch. In the long run this site-preparation principle should cause an insignificant change in the site's water balance and only a slight increase of the speed of organic materi break down.

3. The third step in the analysis is to compare the desired change (1) with the effect of the different site-preparation principles (2). The comparison is made for all site types, and the result will be a list of larger or smaller deviations from the desire results.

The deviations for the factors soil temperature and drainage are combined to express the site-preparation principles' suitability from the point of establishment. In the same way the deviations for nutrient release and hydrology are combined to express the principles' value for long-term productivity.

4. The result of steps 1-3 are then separate gradations of the suitability of the site-preparation principles from the points of establishment and long-term productivity. These gradations are finally pooled for a total evaluation of the different site-preparation principles. In this operation the importance of a goo establishment environment is given a slightly higher weight than the long-term productivity.

One result of the analysis is a regional list of the areas in which a certain site-preparation principle is good or bad. Several principles can have the same total value on a given site type. A second result is a list of the areas and site types for which we still do not have suitable site-preparation methods.

The model has a number of limitations. The risk for frost heaving, insect damage, frost damage, or competition from weeds are examples of biological considerations not included in the model. They must also be considered before a certain site-preparation principle's total biological value can be determined.

The method and the results of the analysis will be presented in publications from the Logging Research Foundation. My presentation has followed a brief description of the method published in a Swedish forestry magazine (Lundmark et al. 1983).

Regrettably, even when all the biological factors have been considered, that is not enough. We do not, as mentioned before, have the techniques necessary to bring about all the site preparations from the theoretical examples on all sites and then there are, of course, a number of nonbiological restrictions to consider. This has made it necessary for the Forest Service to develop our own recommendations, where also, for example, some technical, economical, and environmental restrictions are included. The full recommendations can be found in the Swedish Forest Service's Silvicultural Manual (Domänverket 1982).

An absolute demand with us is, that where there is a need for scarification, the result of the site preparation must be at least the same number of well-distributed planting spots in exposed mineral soil as we need to put out plants. This is usually no problem with the continuously working disk harrows, our most common type of scarifier, but it definitely limits the number of sites on which plows and mound makers can be used.

Not all of our scarification methods,for environmental reasons or because of competing forms of land use, can be applied everywhere. For example, in southern Sweden, where the population pressure on the land for recreational use is heavy, the plow cannot be used. The criticism we would get would not be compensated for by the marginal superiority of plowing over alternative methods on these southern sites. Neither can the method be used on all the suitable areas in the north because of such activities as reindeer husbandry. Access to land areas required by the Lapps and their reindeer would become severely limited, and certain ranges rich in lichens would be ruined.

I regret that I must now introduce two more classifications that we use in our stand description data, for slope and ground roughness.

Slope is self explanatory, I hope:

Slope class	Gradient
1	0-10 %
2	10-20 %
3	20-33 %
4	33-50 %
5	50 + %

Ground roughness is determined by the incidence and size of obstacles on the site. Obstacles refer to:

- depressions that have hard edges and are well defined
- stones, boulders and ground obstructions at least 0,1 m high. N.B. stumps are not counted as obstructions.

Without getting into detail here on the frequencies of different obstruction sizes in the five classes, we then get to a five-grade classification as follows:

Ground roughness: class	
1	Very even
2	Slightly uneven
3	Uneven
4	Rough
5	Very rough

Sites with class 5 slopes and/or ground roughness, and those with both slope and ground roughness 4 cannot be treated with mechanized mthods. The only possible method on these areas is burning, if the method is acceptable by other criteria.

Where slope or ground roughness is 4, and on the more difficult part of the areas with both roughness and slope 3, excavators provide the only possibility for mechanized scarifications. The method is quite expensive and only used on such areas where reforestation would otherwise be impossible or where the total reforestation cost can be lowered by putting in a very expensive but good site-preparation method.

Sites with hardpan are plowed whenever it is technically possible.

For the remaining sites, and they make up a large majority of our land, we have then developed recommendations for the choice of site-preparation method. These sites, which are accessible with regulator-mechanized scarification methods, we divide into two groups: those with easy terrain, i.e. ground roughness class 1 and the better half of 2, and difficult ones.

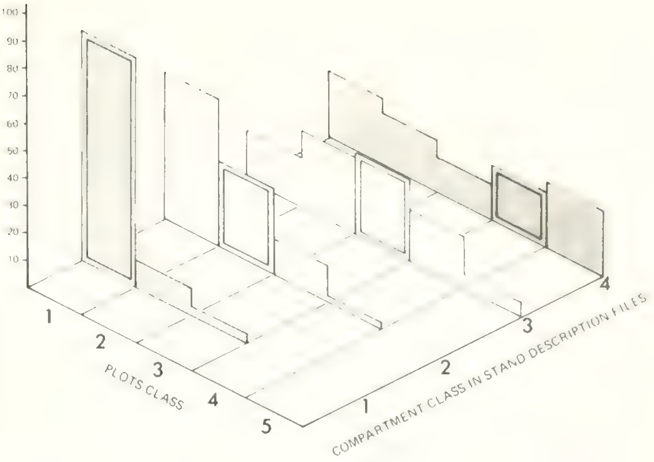

Figure 3.--Variation in ground roughness within the compartment. Average figures from Forest Service files of stand descriptions.

I must here mention two major problems. The data in our stand-description files primarily have reference to logging conditions and are also averages for a very variable reality. To get some information about the variability of our sites, the Forest Service carried out an examination on 65 randomly selected clearcuts, average size 14 ha. On these compartments, we then systematically put out a number of plots, 41 per clearcut in average, on which were measured a number of site factors, e.g. slope, ground roughness, soil-texture class. As expected, there was a tremendous variation around the compartment mean value. See figure 3 for an example.

Because of the two problems mentioned above, it is necessary to make an inspection of the site before applying the recommendations.

In the recommendations the soils have been grouped together, based on their texture and permeability, into three groups:

Soil texture class:

Coarse texture	Gravel and coarse sands
Medium texture	Sand and sandy loams
Fine texture	All finer textures

The part of the recommendation shown in table 1 is for fresh blueberry sites, the most common type in northern Sweden. There are separate recommendations for the northern and southern parts of the country.

Where more than one method is suggested for a site type, the one numbered 1 is the best alternative, then number 2 etc.

The recommendations, which are based on strict forestry considerations, must, of course, only be seen as a help in choosing the site-preparation method and are not imperative in any way. Not everywhere can one find, for instance, all kinds of scarifiers, and there are normally aspects other than forestry to be considered. We do, however, warn against using methods which are not listed, as they tend to be inadequate or too strong.

Try to be flexible when selecting a site-preparation method. In our recommendations the harrows are, for example, a possible alternative on most reforestation sites. This should not be used as a motive for using only harrows indiscriminately. Other methods may be much better on certain site types.

Vegetation class	Soil texture class	Humus layer thickness	Terrain class	No soil scarification	Mound making	Patch scarification	Harrowing	Plowing	Burning	Excavating
Fresh Vaccinium uliginosum	Coarse	< 6 cm	Easy		1	3	2			
			Difficult			2	1			
		> 6 cm	Easy		1		2	1	3	
			Difficult				1		2	
	Medium	< 6 cm	Easy		1		2			
			Difficult				1			
		> 6 cm	Easy		1		2	1	3	
			Difficult				1		2	
	Fine	< 6 cm	Easy		1		3	1	2	
			Difficult				2		1	
		> 6 cm	Easy		1		3	1	2	
			Difficult				2		1	

Table 1. Hard climate zones in interior northern Sweden.

The recommendations are intentionally complete and may seem complicated. On the average site, however, the choice of site-preparation method is not a difficult one, and the recommendations may therefore be reserved for the occasions when one is faced with an unusual combination of site factors.

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Lundmark, J-E et al. Standortsanpassad markberedning - en teoretisk modell. Skogen 3:66-67; 1983.

*GPO 594 - 221 (1985)

Murray, Mayo, ed. Forest classification at high latitudes as an aid to regeneration. Proceedings of the fifth international workshop: 1983 August 15-17; Fairbanks, AK Gen. Tech. Rep. PNW-177. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1984. 56 p.

The proceedings contains seven papers presented at a workshop on regeneration at high latitudes. Reflecting the international nature of the workshops, papers on work in forests of Scandinavia, Canada, and the northern United States were presented.

Keywords: Classification (site), boreal forests, latitude (-site, regeneration (stand).

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Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America

Influences of Recreation

Roger N. Clark, Dave R. Gibbons, and Gilbert B. Pauley

USDA FOREST SERVICE
ANADROMOUS FISH HABITAT
PROGRAM

U.S. Department of Agriculture Forest Service
Pacific Northwest Forest and Range Experiment Station

ABSTRACT

Public and private lands in the United States are used by millions of people for recreational activities. Many of these activities occur in or near streams and coastal areas that produce various species of anadromous fish. A major concern of fishery managers is the possible adverse effect of recreational uses on fish habitat. Conversely, the management of fish habitats may have either positive or negative effects on recreation. This report describes interrelations between recreation and fisheries. Recreational issues affecting either the supply of habitat for anadromous fish production and use, or the demand for the fisheries are also discussed. Opportunities for research are outlined.

KEYWORDS: Recreation, fishing, management objectives, resource impacts, anadromous fish habitat.

USDA FOREST SERVICE
General Technical Report PNW-178

INFLUENCE OF FOREST AND RANGELAND MANAGEMENT ON ANADROMOUS FISH HABITAT IN WESTERN NORTH AMERICA

William R. Meehan, Technical Editor

10. Influences of Recreation

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PREFACE

This is one of a series of publications on the influence of forest and rangeland management on anadromous fish habitat in western North America. This paper describes the interrelation between recreation and the anadromous fishery. Our intent is to provide managers and users of forests and rangelands with the most complete information available for estimating the consequences of various management alternatives.

In this series of papers, we summarize published and unpublished reports and data as well as the observations of scientists and resource managers developed over years of experience in the West. These compilations will be valuable to resource managers in planning uses of forest and rangeland resources, and to scientists in planning future research.

Previous publications in this series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.

2. "Impacts of natural events," by Douglas N. Swanston.

3. "Timber harvest," by T. W. Chamberlain.

4. "Planning forest roads to protect salmonid habitat," by Carlton S. Yee and Terry D. Roelofs.

6. "Silvicultural treatments," by Fred H. Everest and R. Dennis Harr.

7. "Effects of livestock grazing," by William S. Platts.

8. "Effects of mining," by Susan B. Martin and William S. Platts.

9. "Forest chemicals," by L. A. Norris, H. W. Lorz, and S. V. Gregory.

11. "Processing mills and camps," by Donald C. Schmiege.

12. "Rehabilitating and enhancing stream habitat: 1. Review and evaluation," by James D. Hall and Calvin O. Baker.

13. "Rehabilitating and enhancing stream habitat: 2. Field applications," by Gordon H. Reeves and Terry D. Roelofs.

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COMMON AND SCIENTIFIC NAMES OF FISHES MENTIONED IN TEXT AND TABLES[1]

Common name	Scientific name
Shad	FAMILY Clupeidae
	FAMILY Salmonidae
Pink salmon	*Oncorhynchus gorbuscha* (Walbaum)
Chum salmon	*Oncorhynchus keta* (Walbaum)
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Sockeye salmon (kokanee)	*Oncorhynchus nerka* (Walbaum)
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)
Golden trout	*Salmo aguabonita* Jordan
Cutthroat trout	*Salmo clarki* Richardson
Rainbow (steelhead) trout	*Salmo gairdneri* Richardson
Brown trout	*Salmo trutta* Linnaeus
Arctic char	*Salvelinus alpinus* (Linnaeus)
Dolly Varden	*Salvelinus malma* (Walbaum)
Inconnu (sheefish)	*Stenodus leucicthys* (Guldenstadt)
Smelt	FAMILY Osmeridae
	FAMILY Percichthyidae
Striped bass	*Morone saxatilis* (Walbaum)

---

[1] From "A List of Common and Scientific Names of Fishes from the United States and Canada," American Fisheries Society Special Publication 12, Fourth Edition, 1980, 174 p.

INTRODUCTION

Topics covered in this report have potential for intense conflict. Habitats used during critical periods in the life cycle of anadromous fish are generally in the same aquatic and riparian ecosystems in which productive timber stands and wildlife habitat are found. Important recreational opportunities are also in these same areas.

In this paper, we discuss current knowledge on the relation of recreational use to the anadromous fishery--that is, fish and their habitats. The main emphasis is on how recreational use and management directly affect fish habitats, but the implications of fishery management for recreational opportunities and use are also briefly discussed. The information provided in this paper should be valuable in evaluating the consequences of recreational uses and management on the anadromous fishery.

Recreation has direct effects on the fishery, as well as indirect effects through habitat changes. For example, roads and silvicultural treatments may affect both the nature and extent of recreational use, which can lead to additional effects on the fishery. Consequently, we will draw from other papers in this series to develop an understanding of the interrelations between recreational use and the anadromous fishery.

We used three bases for our conclusions: empirical evidence about recreational use and its relation to fish habitats (we will use research that focused on non-anadromous fish as well); existing concepts, theories, and frameworks; and our judgments, based on current knowledge and experience. This report is based on our current perceptions. Continuing professional debate, management experience, and formal research will determine how well the assumptions we make and the conclusions we draw fit real conditions.

OBJECTIVES

The objectives of this paper are to:

- Review new knowledge about the relations of recreation to the anadromous fishery.
- Describe an approach for integrating the recreational and fishery systems.
- Identify links among recreation, anadromous fisheries, and other forest resource systems (for example, timber, wildlife, and forage).
- Establish a basis for evaluating effects of alternative recreation-management options on the anadromous fishery and alternative fishery-management strategies on recreation.
- Outline research needed to improve understanding of recreation-fishery interactions.

DISTRIBUTION OF THE ANADROMOUS FISHERY

Salmonids (salmon and trout) have probably received more attention, both culturally and economically, over a longer time and greater geographic area than any other group of fishes. Ten species of anadromous salmonids are found on the west coast, including five Pacific salmon--chinook, coho, chum, sockeye, and pink; three trout--steelhead, brown, and cutthroat; and two char--arctic and Dolly Varden. Salmon support a large commercial fishing industry; salmon, trout, and char support a valuable sport fishery. These fish are indigenous to the coastal area bordering the North Pacific Ocean that extends from Northern Japan and the USSR in Asia, to the Arctic Ocean and down the coast of North America from Alaska to California (fig. 1). Anadromous salmonids still occur throughout much of their original range, but their numbers in some locations have been greatly reduced by overfishing, habitat degradation, and natural climatic changes. Many millions of adult anadromous salmonids are still produced in the waters of the western United States, including USDA Forest Service Regions 1, 4, 5, 6, and 10 (encompassing about 35 National Forests). This production is fished commercially, for subsistence, and for sport. The centers of abundance vary according to species and even within species. For example, sockeye salmon are most abundant in Alaska (table 1)--specifically in Bristol Bay, waters near Kodiak Island, and Cook Inlet.

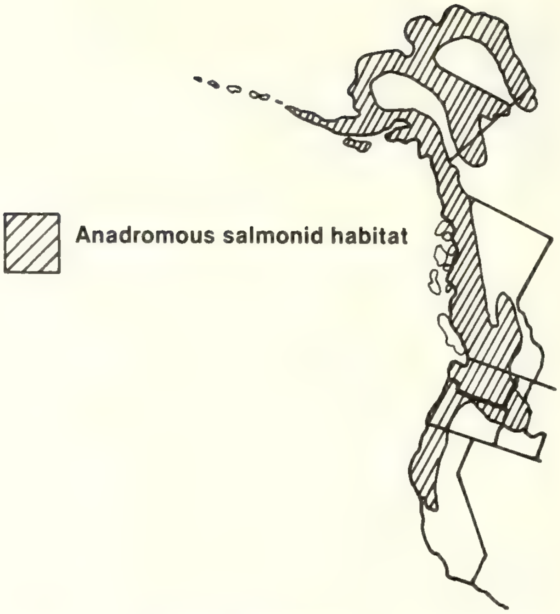


Figure 1.--Distribution of anadromous salmonid habitat in western North America.

Anadromous salmonids use both freshwater and marine environments, and they all have exacting habitat requirements. All species reproduce in fresh water, and most rear there before migrating to sea (as smolts) where they mature (fig. 2). Freshwater habitat requirements differ slightly, but all species share some common requirements. For optimum production, all of them require cool, flowing waters; migratory access to and from the sea; clean gravel substrate for reproduction; high levels of dissolved oxygen in streams, lakes, and intragravel environments; sufficient instream cover; and food organisms. Species preferences for these requirements vary slightly (Reiser and Bjornn 1979).

Table 1—Present occurrence of anadromous salmonids in western North America[1] [2]

	Region					
	Continental United States				Canada	Alaska
Species	California	Oregon	Washington	Idaho	British Columbia	Alaska
Pink salmon	Rare to absent[3]	Rare to absent	Present	Absent	Abundant	Predominant
Chum salmon	Rare	Few	Present	Absent	Abundant	Predominant
Sockeye salmon	Rare	Rare to absent	Few	Rare	Abundant	Predominant
Chinook salmon	Abundant	Abundant	Predominant	Present	Abundant	Present
Coho salmon	Present	Abundant	Abundant	Few	Predominant	Abundant
Cutthroat trout	Present	Predominant[4]	Abundant	Absent	Present	Present
Rainbow trout (steelhead)[5]	Abundant	Abundant	Predominant	Present	Abundant	Present
Brown trout	Few[6]	Absent	Absent	Absent	Absent	Absent
Dolly Varden[7]	Absent	Few	Present	Absent	Present	Predominant
Arctic char	Absent	Absent	Absent	Absent	Few[8]	Predominant
Percent usable spawning habitat vs. historic[1] [9]	50	75	75	50	100	100

Sources
[1] Atkinson and others (1967).
[2] Scott and Crossman (1973).
[3] McPhail and Lindsey (1970).
[4] Giger (1972).
[5] Sheppard (1972).
[6] Burton (1982).
[7] Clemens and Wilby (1961).
[8] B.C. Ministry of Environment (1981).
[9] Fry (1973).

Definitions
Absent - no fish present.
Rare to absent - occur rarely.
Few - occur occasionally.
Present - supports fishery.
Abundant - readily harvestable numbers.
Predominant - numbers used surpass all others (by region).

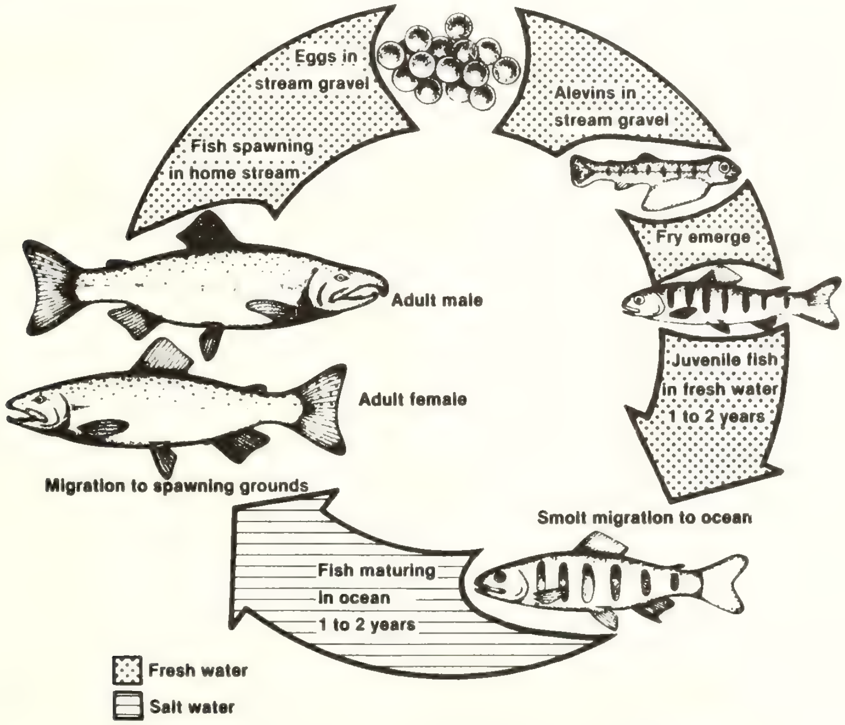

Eggs in stream gravel
Alevins in stream gravel
Fry emerge
Juvenile fish in fresh water 1 to 2 years
Smolt migration to ocean
Fish maturing in ocean 1 to 2 years
Migration to spawning grounds
Adult female
Adult male
Fish spawning in home stream
Fresh water
Salt water

Figure 2.--Typical life cycle of anadromous salmonids.

Table 2—Availability and use of anadromous fisheries on National Forests

Item	West coast (U.S.A.)	Alaska
Miles (kilometers) of stream:		
All fisheries	71,000+ (113 600+)	31,000+ (49 600+)
Anadromous fisheries	43,000+ (68 800+)	30,000+ (48 000+)
Number of fishing trips, anadromous fish	1,921,400	1,427,600

Source: Sport Fishing Institute (1982).

Because of the extensive and variable movements of these fish in the sea, a better picture of the United States distribution is presented by looking at their natal stream habitat. On National Forest lands in southeastern Alaska, anadromous fish are found in over 4,850 streams, which have a length totaling more than 30,000 miles (48 270 km), and 120,000 acres (48 560 ha) of lakes (Everest and Summers 1982). National Forest lands in the West have over 43,000 miles (69 200 km) of streams producing anadromous salmonids annually (USDA Forest Service 1982), and provide about 1,921,400 recreation visitor days (Sport Fishing Institute 1982) (table 2).

Alaska, by having more than 36 times as much freshwater habitat per resident than any other western State, has the greatest potential for fish and angling. Washington, Oregon, and Idaho will have trouble maintaining their present fish production because the construction of hydroelectric dams on the Columbia River has eliminated half of the potential spawning habitat of anadromous fish (Rettig 1980). The 1980 Northwest Power Act is an attempt to stabilize fish production by providing for the protection and maintenance of anadromous fish that use streams with hydroelectric developments. California is the only western State that has an excessive demand for sport fishing, and it has the least of its original fishing habitat accessible. California is the most populous State; it has many new water-development projects planned. The percentage of Californians who sport fish will probably decline because of the reduction of the aquatic habitat needed to produce anadromous fish, which will increase fishing pressure and lead to angler dissatisfaction.

Using artificial propagation is one of the primary issues related to the supply of anadromous salmonids. Historically, salmon and trout from hatcheries have been used to replace lost natural production and to supplement natural producton where the demand for certain species is high. In Oregon and Washington, about 65 salmon and 31 steelhead hatcheries are thought to be supplying about 50 percent of the total production of these fish. Some of these hatcheries are very successful, and others are not. Although hatcheries can produce substantial quantities of salmon and trout, they can be subject to or cause problems, including: high capital and operating costs; disease problems both in the hatchery and by contamination of natural stocks; high probability of major genetic changes both in the hatchery stock and in natural wild stocks through interbreeding; breeding of a "nonbiting" fish that more efficiently escapes both the commercial and the recreational fisheries; and difficulty of harvesting the excess supply of hatchery fish without overharvesting natural stocks with which they mingle (continual planting of hatchery fish stimulates an increase in fishing effort that will persist as long as the catch remains within a satisfactory range).

Artificial production can play an important role in moderating changes in the environment, but it is a less desirable alternative than the natural production of anadromous salmon and trout.

THE MULTIRESOURCE SYSTEMS PERSPECTIVE

The relation between recreation and the anadromous fishery is inherently complex, representing an interaction among people, various resources, and the uses of those resources. For example, not only may recreational use directly affect fish and their habitat, but other resource uses (such as timber harvesting and road building) may affect recreational use, which may lead to additional effects on the fishery. Consequently, to understand how recreation and anadromous fisheries are related requires a multiresource perspective. Recreation specialists can use this perspective to avoid or solve conflicts and to identify and use positive opportunities. Some of the basic parts of this complex system are illustrated in figures 3, 4, and 5.

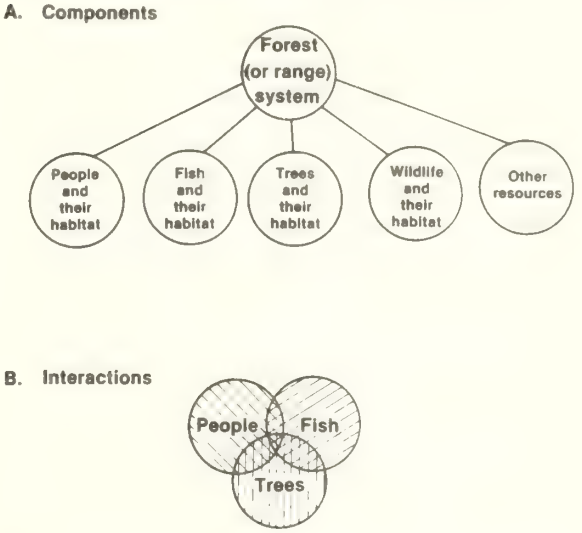


Figure 3.--Resource components and interactions in a forest-resource system.

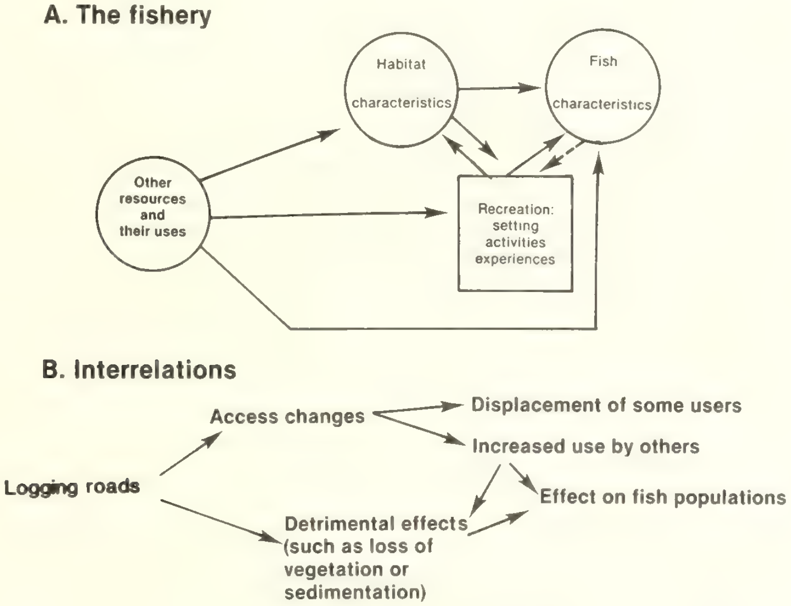

A. The fishery
Habitat characteristics
Fish characteristics
Other resources and their uses
Recreation: setting activities experiences
B. Interrelations
Logging roads
Access changes
Displacement of some users
Increased use by others
Effect on fish populations
Detrimental effects (such as loss of vegetation or sedimentation)

Figure 4.--Interactions of the anadromous fishery and recreation.

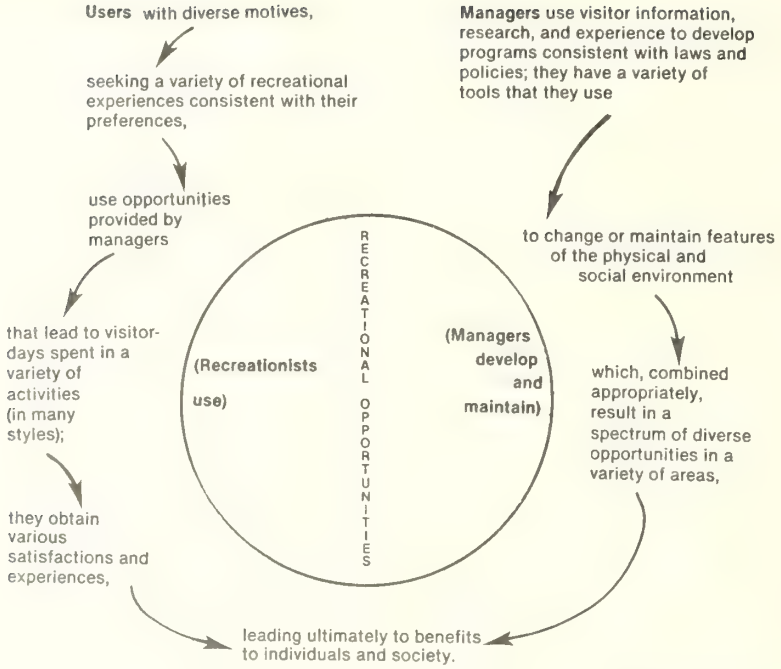

Users with diverse motives,
seeking a variety of recreational experiences consistent with their preferences,
use opportunities provided by managers
that lead to visitor-days spent in a variety of activities (in many styles);
they obtain various satisfactions and experiences,
leading ultimately to benefits to individuals and society.
Managers use visitor information, research, and experience to develop programs consistent with laws and policies; they have a variety of tools that they use
to change or maintain features of the physical and social environment
which, combined appropriately, result in a spectrum of diverse opportunities in a variety of areas,
(Recreationists use)
RECREATIONAL OPPORTUNITIES
(Managers develop and maintain)

Figure 5.--Link between desires of recreationists and opportunities provided by managers.

The basic social and biological communities present in most areas (fig. 3a) cannot exist without influencing or being influenced by the others (fig. 3b). Most management and research have focused on people or fish or trees, but most of the controversy and problems in resource management are found in the areas of overlap. We know the least about where the various physical and biological systems overlap--and interact.

We will discuss the area where all these interests come together. This simple idea is expanded (fig. 4) to separate the two basic anadromous fishery components (habitat and fish) and recreation, which includes settings ("people habitat"), recreational activities, and recreational experiences. Recreation may affect both fish habitat and fish populations (fig. 4a). Some fish-habitat management programs may affect recreational use as well, either positively or negatively. Other resource uses, such as logging, may have a negative or positive influence on certain types of recreational opportunities and may subsequently affect the fishery system.

Roads built for logging (fig. 4b) may directly cause increased sedimentation, which adversely affects fish survival. Roads also provide access for recreationists that may lead to changing patterns of use in an area (desirable to some people, undesirable to others). Changed or increased use may have either detrimental effects on the fish populations (reduction in stock below optimum) or on fish habitat (loss of vegetation, increased sedimentation), or positive effects on fish populations (harvest limited to reproductive surplus).

The system we are examining is not simple. We will use the general relations briefly presented here to organize current knowledge about recreational effects on anadromous fish.

THE RECREATIONAL SYSTEM

In this section, we describe recreational characteristics that provide a background for evaluating recreational effects on the fishery. We assume that an understanding of people's motives will help in the evaluation and prediction of potential effects on fish habitat.

COMPONENTS

When considering opportunities for outdoor recreation, people choose the setting, the activities, and the kinds of experiences to seek (fig. 5). We will focus on the recreational setting because it is the point of contact between recreation and fishery habitat. Recreationists who have information describing the factors that influence or define the range of possible recreation settings will be in the best position to make recreational choices (Clark and others, in press).

WHAT WE KNOW ABOUT OUTDOOR RECREATION

Since the 1950's, research has addressed recreation in general, as well as specific activities, such as fishing. We will identify some basic conclusions and principles from those studies on interactions between recreation and anadromous fisheries. All recreational activities occurring in areas that support the anadromous fishery will be considered.

In both the formal and popular literature related to outdoor recreation, terms such as motives, satisfactions, and experiences are commonly used, sometimes ambiguously. The definitions used in this paper are as follows:

Motives--the underlying reasons for engaging in a recreational pursuit (for example, health, relaxation, and strengthening of family ties).

Preferences--the favored alternatives for activities, experiences, or setting attributes.

Expectations--conditions presumed to be encountered during recreation (expectations are based on previous knowledge and experience).

Opportunities--chances for recreation, consisting of:
  Settings--the combination of social, managerial, and natural features that give recreational value to a place.
  Activities (uses)--various ways that people behave in their leisure time.
  Experiences--the products resulting from participation in a recreational activity or set of activities in a particular setting.

Satisfaction--the enjoyment that people derive from participation in various recreational pursuits.

The following generalizations suggest how people relate to recreational opportunities and areas that may sustain an anadromous fishery.

1. Recreationists' preferences and motives span a range of settings.

People use particular locations for different reasons. Water, whether in lakes, streams, or oceans, is an important component in recreational choices (Clark and others, in press; Lime 1971; Lucas 1964). Forests, fish, and wildlife also play a key role for many people.

Managers should not presuppose what a particular recreation user finds desirable about specific recreational sites or recreational settings in general. For example, a variety of preferences may be related to users' choices to use areas considered to be habitat for anadromous fish. Anglers will, of course, prefer the presence of fish; however, other attributes--such as a place to camp, parking for vehicles or boats, or a place for family and friends to get together--may be important enough to take precedence over fishing. The extent to which people prefer to engage in activities away from the site will also influence their decision.

2. Recreational activities are diverse.

Recreationists can take part in a wide variety of activities; for example, hiking, camping, boating, hunting, and off-road-vehicle use can all take place in fishing areas. In common among such activities are the base resources used, the number of people using them, and the type of management provided. The fact that a stream with an abundant anadromous fishery is present does not mean fishing will necessarily be the primary use of the area. The river (or lake) may be important to all users, but the fish may be critical for only some of them. Furthermore, most recreational outings are composed of several activities and an individual's decisions regarding where to go may vary from trip to trip depending on the "primary" purpose of the trip.

When recreational effects on the anadromous fishery are studied, all activities in the areas influencing fish habitats (riparian and related uplands, as well as the aquatic areas) must be considered. Whether a person is standing on a bank fishing or standing on a bank taking photos makes little difference. Important considerations related to all recreational activities are: where they take place in relation to fish habitat (upland, on bank, in water), when they occur (seasons, stage of fish's life cycle), the duration of the activity, the number of people in an area (intensity of use), and how widespread the use is over an area (extent of use).

3. Activities cannot be equated with motives for recreation or resulting experiences.

Recreation managers have concluded that people can have different motives for engaging in the same activity (such as fishing). Motives may include nature appreciation, interaction with other people, challenge, relaxation, and even catching fish. But catching fish (or shooting game) is not necessarily related to satisfaction and enjoyment (Brown 1982, Hendee and others 1977, Potter and others 1973). This knowledge is significant when attempts are made to change patterns of recreational use. Changing these patterns by managing the fishery (increasing or decreasing stocking, changing species composition) will affect only people whose primary motive is catching fish.

Recreationists are satisfied with a particular trip or activity when pretrip expectations are consistent with what they encounter (Clark and Stankey 1979b, Roggenbuck and Schreyer 1977). A high degree of satisfaction can also occur when recreationists are able and willing to modify their plans whenever expectations are not met.

Anadromous fishery habitats can be more effectively managed when the motives of those using them are known. If recreational values are the major reason for fishing, then the fish take a secondary role. When fishing is a trophy or subsistence activity, then the taking of fish is the primary concern. Understanding of various motives for fishing will allow managers to develop strategies consistent with users' values.

4. Access is an important influence on recreational choices, and the location and amount of recreational use.

Of all management factors identified by Clark and Stankey (1979a) in the Recreation Opportunity Spectrum (ROS), access probably plays the most critical role in either facilitating or hindering recreational use. Roads facilitate recreational preferences at the "modern-urban" end of the ROS. Road access will hinder recreational opportunities that are not compatible (necessary or desired) with roads. Decisions made about roads--needs, location, and type--are not usually made with recreational objectives in mind. Yet, road construction and use may have major detrimental effects on anadromous fish habitats (Gibbons and Salo 1973, Yee and Roelofs 1980). Best management practices have been developed to minimize these effects (Yee and Roelofs 1980). Later in this paper we will discuss considerations for identifying and evaluating both positive and negative implications of access management alternatives.

5. Most people take recreational trips in areas near their communities.

Studies in Alaska demonstrate that most recreational trips by residents are taken in areas around communities (Clark and others 1982). A "home range" exists that is based on type of access and time of travel. In southeastern Alaska, the home ranges for the various communities are generally independent of one another. By understanding the relation between recreational users and available recreational opportunities, resource managers can better predict the consequences of their policies and actions. Some changes by management may have significant effects on patterns of recreational use in areas considered as anadromous fish habitat.

6. Managers and recreationists disagree about the importance of recreational effects.

Studies show that resource managers have a greater concern for the effects of recreation than do recreationists (Clark and others 1971, Clark and Stankey 1979b, Downing and Clark 1979, Lucas 1979). Managers' values differ from those of many users. Because of their training and experience in natural resources, most managers prefer to see recreational areas remain relatively undisturbed. Recreation managers are more likely to favor the more "primitive" end of the Recreation Opportunity Spectrum than are many users. Managers are also likely to have a longer and more intense experience with the effects of recreation than are most users and may be more sensitive to resource changes.

Managers should recognize that such disparities exist and attempt to accommodate user perspectives and educate users concerning the problems that may be created by recreational activities. Each group must understand how the other relates to resource changes before any effective controls can be developed and carried out.

7. The same activity may take on different styles.

People can participate in the same recreational activity in a variety of ways and in places that range from city parks to wilderness. An activity such as hiking is basically the same in all areas, but the motives for engaging in the activity, the style of participation, and the resulting experiences can differ dramatically from one area to another.

Fishing is a good example. Bryan (1976) describes four types of anglers:

> Occasional--novice ability and interest in the sport; any fish will do as long as the challenge is not too difficult.
>
> Generalist--focus on catching numbers of fish by any means or tackle.
>
> Tackle-species specialists--specialize in method (for example, fly-fishing) and species (for example, steelhead); importance placed on the skill and the esthetic quality of the experience, as opposed to catching and keeping fish.
>
> Method-species-setting specialists--specialize in method, species, and setting (spring or meadow streams); preoccupation with skill and overall quality of experience; tend to center much of life around leisure activity.

As the anglers move from the "occasional" to the "method-species-setting specialist," they become more particular as to species, technique, tackle preferences, and setting requirements. Two different philosophies of fisheries management can be used to meet these varied demands: managing the indigenous salmonid populations as part of the natural ecosystem, in which harvest is limited to the reproductive surplus, or the intensive stocking of hatchery fish to build up the fishery. The first option depends on maintenance of the stream habitat to produce fish, and fishery regulations to provide adequate fish escapement. Anadromous fish have remarkable powers to replenish their numbers. As long as stream conditions remain favorable to their individual requirements, many native fish can be harvested without endangering brood stocks. The second option, to use many hatchery fish to increase fish populations, responds to the first two angler types. These anglers generally are concerned more with the number of fish taken than with the quality of the fishing experience.

INTERRELATIONS BETWEEN RECREATION AND THE ANADROMOUS FISHERY

Recreation may affect fish and their habitat, and fishery management influences recreation. We have made an attempt to identify all the potential influences, but because information about the nature and extent of such influences is limited, evaluation of their importance will have to be made case by case.

EFFECTS ON THE FISHERY FROM RECREATION

ZONES OF INFLUENCE

Recreation can affect the fishery in four basic zones--coastal marine, estuarine, riparian-stream, and lake. Various recreational activities have both direct and indirect effects on the fish and their habitats in these locations. Recreational activities occur at the edges of fish habitat zones (lakeside, streamside, and seaside) and in the water in all zones. The importance of effects on the fishery from recreation are shown in table 3.

Table 3—Importance of recreational activities to anadromous fish and fish habitats

Zone of influence	Effects on fish populations	Effects on habitat
Marine:		
Coastal (open ocean)	(X)	0
Estuarine	(X)	0
Freshwater:		
Streams	X	X
Lakes	X	(X)

0 = none likely.
(X) = possible minor effect.
X = possible major effect.

DIRECT EFFECTS ON FISH

In all of these zones, recreational effects on fish occur primarily through fishing. Adult fish of various species (all the anadromous salmonids, smelt, striped bass, shad, and sheefish) are the primary targets of anglers. Fishing, depending on the available fish population and the intensity of fishing, may have either minor or major adverse influences on the fish. Hooking, even if the fish are released, can result in injuries and diseases that may lead to death. Handling hooked fish before releasing them also contributes to mortality. The combination of effects on the fish from harvesting or hooking and releasing can influence the size and species composition of populations. Recreational activities other than fishing apparently do not directly affect fish.

EFFECTS ON FISH HABITAT

The ways in which recreation may influence elements making up the habitat of anadromous fish are summarized in table 4. Recreation is considered in two ways--the factors defining the recreational setting (habitat) and the recreational activities taking place. We have attempted to isolate recreational components that appear related to elements of fish habitat. The habitat requirements of anadromous fish are complex, but are condensed here into four principal components--cover, food, space, and spawning area. These four habitat components are associated (table 5) with migration, spawning, incubation, and rearing, and the habitat zones of influence.

Table 4—Effects from recreational activities by zones of influence

	Upland			Riparian			
	Vegetation			Vegetation			
Activities	Overstory	Understory	Soils	Overstory	Understory	Soils	Aquatic
Hiking	(2)	(1)	(1)	(2)	(1)	(1)	(2)
Horses	(2)	(1)	(1)	(1)	(1)	(1)	(2)
Vehicles:							
On roads	—	—	(2)	(2)	(2)	(2)	(2)
Off roads	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Camping	(1)	(1)	(2)	(1)	(1)	(1)	(1)
Fishing	—	—	—	(2)	(1)	(2)	(1)
Boating	—	—	—	(2)	(1)	(1)	(1)
Waterplay:							
Swimming	—	—	—	(2)	(2)	(2)	(1)
Temporary dams	—	—	—	(2)	(2)	(2)	(1)
Removing debris	—	—	—	(2)	(2)	(2)	(1)
Bathing, dishwashing	—	—	—	(2)	(2)	(2)	(1)

(1) = primary effects.
(2) = secondary effects.

Table 5--Relations of zone of influence to the freshwater habitat requirements and life cycle of anadromous salmonids

	Habitat requirements/freshwater life-cycle phases[1]			
Zone of influence	Cover/ migration	Food/ spawning	Space/ incubation	Spawning substrate/ rearing
Upland:				
Vegetation	0/0	0/0	0/0	2/0
Soils	0/0	0/1	0/1	2/0
Riparian:				
Vegetation--				
Understory	1/0	1/0	0/0	0/1
Overstory	1/0	1/0	2/0	0/1
Soils	2/0	0/1	2/1	1/2
Aquatic:				
Vegetation	1/2	1/0	0/0	0/1
Streamflow	2/1	2/1	1/1	1/1
Channel morphology--				
Riffles	2/0	1/1	2/1	1/2
Pools	1/2	1/0	1/0	0/1
Water quality--				
Suspended sediment	2/2	1/0	0/0	0/1
Bedload sediment	1/0	1/1	1/1	1/1
Temperature	0/1	1/1	0/1	0/1
Dissolved oxygen	0/2	2/1	2/1	0/1
Bacteria	0/0	2/0	0/2	0/2
Chemicals	0/2	1/1	0/1	0/1
Barriers	2/1	2/2	2/0	0/2
Debris	1/1	2/2	0/0	0/1

[1] First number is related to habitat requirements; second number is related to life-cycle phase. 0 = none anticipated; 1 = primary effect; 2 = secondary effect.

The literature, our professional experience and judgment, and common sense suggest that certain combinations of recreational factors defining settings, coupled with specific activities, may affect anadromous fish habitat. Whether the possible effects we identify are important cannot be readily determined. Resource managers will have to evaluate the consequences of encouraging or discouraging individual recreational uses.

In the riparian zone, such activities (as well as management actions that support them) may alter habitat elements important to anadromous fish populations. Recreational use of the riparian zone does not always disrupt anadromous fish habitat significantly, however. Both the size and importance of effects must be taken into account in evaluating whether intolerable effects have occurred.

EVALUATING THE EFFECTS FROM RECREATION

Recreational effects differ by region, river type, vegetation and soil conditions, season, and the nature and extent of recreational use. Evaluation of these effects is largely judgmental; seldom are definitive answers available to allow accurate prediction.

Some of the patterns of recreational use that should be considered when evaluating its effects are: temporal variation (daily, weekly, seasonally, duration); intensity of use (concentrated use, dispersed use); spatial distribution (upland--on or off road; riparian; and in water--ocean, estuary, stream, or lake).

Questions that need to be addressed when evaluating the significance of recreational effects include:

- Do use and resulting effects coincide with areas of key fish production?
- Is the effect serious enough to create a change in habitat components? Will the change be quick or slow to occur? Will it be a long- or short-term change? Are cumulative effects likely?
- Are the recreational uses and any resulting effects concentrated in only a small portion of the stream or are they widely dispersed?

Answering these and other related questions will help determine whether any action will be required to prevent or ameliorate further changes in fish-habitat conditions.

Some general observations about recreational use and its relation to anadromous fish habitat are:

- Recreational use is not uniform in its distribution over either time or space--water generally draws and concentrates use.
- The amount of use is not necessarily directly related to the effects on the area. Sometimes the practices of the individual or party in an area are more important than the number of people (Aitcheson and others 1977).
- Most of the change in vegetation results from initial light use (Cole 1979).
- Anglers can significantly affect upland and riparian habitat in addition to directly affecting fish populations because they spend a lot of time in other activities, such as sightseeing, walking, and camping.

When existing or potential effects along a stream are evaluated, knowing how they differ may be useful. Some of the ways effects can differ are: probability of occurrence (likely, unlikely), distribution (intensity, extensity), magnitude (minor, major), duration (short term, long term), recovery (quick, slow), and location (instream, riparian, upland).

A guide for judging the severity of effects from recreational use is shown in figure 6. We believe that by considering both the intensity and extensity of effects, actual or potential effects can be ranked. We believe that "severe" impacts have seldom occurred because of recreation.

After the severity of the possible recreation effects is determined, the manager has several options. When the effects exceed what is acceptable to management objectives, the manager can:

- Do nothing, thereby accepting the consequences of the use or uses in question.
- Mitigate the effects by limiting or eliminating use in critical areas through regulation or by changing site design.
- Redefine fishery objectives for all or part of the area (recreation might be more important than fishery values).
- Use a combination of the second and third alternatives.

Managerial decisions will require judgments about the consequences and feasibility (biological, social, and political) of each alternative. Information about the size of the effect on anadromous fish habitat and the importance of the change for various resource uses, including recreation, will be helpful in making judgments.

		Intensity		
		High	Low	None
Extensity	High	SEVERE	SERIOUS	
	Low	MODERATE	MINOR	
	None			

Intensity--amount of disruption (change) per unit area of a stream

Extensity--proportion of stream that is affected

Figure 6.--Effects of existing or potential recreational use along portions of a stream.

GENERAL EFFECTS OF RECREATION ON ANADROMOUS FISH HABITAT

Little documentation exists regarding specific effects of recreation on anadromous fish habitat. Some research--briefly summarized here--has been conducted on the effects of recreation on soils and vegetation in general and along streams in particular. We also speculate about how recreation can affect other environmental factors listed in table 5, and the implications such changes have for anadromous fish in various stages of their life cycle.

We believe recreational use can affect anadromous fish habitat in the following ways:

- Upland changes in soils and vegetation that may affect runoff and erosion.
- Riparian changes that influence erosion, cover, food sources, and water quality.
- Instream changes that affect stream morphology, water quality, stream flow, substrate, and debris.

The nature and extent of such potential changes differ by the intensity and extensity of recreational use.

UPLAND SOILS AND VEGETATION

Changes in vegetation from recreational activities in upland and riparian areas appear to be generally similar to effects of livestock grazing (see Platts 1981 for a discussion of the effects of livestock grazing). Cole (1979) discussed problems in studying recreational effects on vegetation and concluded that most change results from initial light use. Continued or increased recreational use at sites may have little additional effect.

Settergren's (1977) review identified six possible effects on soils of recreation along rivers: compaction, root exposure, destruction of the soil profile through loss of vegetation, reduction in organic matter, increased bulk density, and decreased soil moisture. He concluded (in agreement with Cole) that the greatest compaction occurs immediately after an area is opened for use, after which the soil tends to stabilize. As soil compaction and vegetation loss occur, erosion may accelerate. This can decrease the depth of soil profiles and expose roots.

Landform patterns in upland and riparian areas may also be affected by recreational use. Hiking and use of off-road vehicles or horses may create ruts and trails that gather runoff, leading to increased erosion. Whether such changes will occur, or to what extent, depends on local soils, vegetation, topographic conditions, and the proximity of the damage to riparian areas.

Settergren's (1977) review also described five types of vegetation changes: mortality of overstory, loss of tree vigor, mechanical injury, root kill, and loss of ground cover. Recreational activities can cause direct physical or mechanical injury and indirect physiological and morphological changes by affecting the soil. Settergren concluded that mechanical injury is common, increasing the likelihood of disease and possible subsequent mortality. Decline in tree vigor is sometimes associated with soil degradation, and reduced ground cover (both total amount and number of species) is one of the first signs of recreational use. Settergren believes a shift towards fewer, more tolerant species may occur when vegetation is adversely affected by recreational uses.

The consequences of these changes on the quality of fish habitat are uncertain. Vegetation loss may lead to soil loss, compaction, or both; increased sedimentation; and reduced fish spawning habitat. No research has been specifically conducted establishing whether, or under what conditions, such results might occur.

RIPARIAN

The USDA Forest Service defines a riparian ecosystem as "a transition between the aquatic ecosystem and the adjacent terrestrial ecosystem and is identified by soil characteristics and distinctive vegetation communities that require free or unbound water." For management purposes, riparian boundaries are defined as "the land and vegetation extending at least 100 feet measured horizontally from the edges of all perennial streams, lakes, and other bodies of water" (USDA Forest Service 1980).

When potential effects from recreational activities are evaluated, local conditions affecting the size of the riparian area must be considered. Substantial differences in the recreational use and its effects can occur in areas where the actual riparian area is 300 feet rather than 5 feet wide. In general, greatest disruptions are likely to occur within 15 feet of the stream. Thus, our definition of the riparian zone is the area of land and vegetation that provides a transition between the aquatic and terrestrial environments, and directly influences the stream.

Streamside vegetation directly influences the quality of anadromous salmonid habitat. Riparian vegetation provides shade and an insulating canopy, preventing adverse water temperatures during both summer and winter. It also acts as a filter to prevent addition of sediment, and its roots provide streambank stability and cover for rearing salmonids. Riparian vegetation directly influences the food chain of a stream ecosystem by providing organic detritus and terrestrial insects, and by controlling aquatic productivity that depends on solar radiation.

Understory.--Understory vegetation can be reduced or removed when recreational activities occur along the edge of rivers and lakes, depending on the intensity and type of activity. Loss of understory vegetation directly affects the rearing habitat of salmonids by reducing hiding cover, food production, and streambank stability. Food sources for anadromous fish may be affected in different ways. Loss of streamside vegetation resulting from recreational use will affect insect habitat. Chemicals used for insect control in developed campgrounds will reduce available insect populations.

Undercut banks.--Banks can be destroyed whenever recreational activities take place near the shore of rivers and lakes. How quickly bankloss occurs and how much of the shoreline will be affected depends on the type of recreational activity taking place and its frequency. Use of off-road vehicles and horses will generally be more disruptive than foot travel. The addition of sediment directly affects spawning gravels, and the loss of undercut banks has a negative effect on rearing areas.

Overstory.--In addition to directly affecting cover, food, and streambank stability as the understory does, the overstory provides shade, resulting in increased rearing space and the cool waters that favor growth of salmonids.

AQUATIC

Vegetation.--When some measure of stabilization of the stream bottom is reached, the substrate becomes habitable for plants and animals. The presence of macro-aquatic vegetation (such as mosses and lily-pads) signifies a stable environment. Habitat is affected when the sedimentation rate or volume of streamflow is changed by either indirect recreational activities or removal of the aquatic vegetation. These effects may be temporary or permanent, depending on the type and duration of the activity. Loss of vegetation can affect fish production by removing cover and reducing available food.

Streamflow.--Significant changes in streamflow can occur as a result of recreational activities, including placement of rocks and debris in the stream, and diversion or impoundment of water. Rocks and debris can be beneficial for fish rearing if they are added in moderate quantities. Large additional quantities, however, can result in channel instability and streambank erosion. Reduction in streamflow, as a result of diversion or by dams, is a common problem that can be directly detrimental to both spawning and rearing habitats. Reduced streamflow can impede or block both downstream smolt movement and upstream adult migration, increase water temperatures, and reduce available rearing and spawning habitat.

Channel morphology, riffles.--The depth and flow of water over and through riffles defines the quality of spawning habitat for the various species of salmonids. Activities such as swimming, boating, and instream use of off-road vehicles can affect riffle quality. Swimming-hole construction or enlargement and streamflow concentration for boat passage can disturb habitat and fish. If the quality of riffle areas decreases, production of usable food will also decrease.

Channel morphology, pools.--A pool is generally deeper and sometimes wider than the average width and depth of the stream, and its velocity is slower than the immediate upstream and downstream segments. Pools are used by salmonids for rearing and for resting during migration. Pools can also be used by recreationists for swimming, boating, suction dredge mining, bathing, and other activities. A change in pool character (depth, width, debris) generally results in a decline in salmonid populations. Pool character is affected most often by a change in the quantity of cover (logs, limbs, rocks, and undercut banks).

Water quality, suspended sediment.—The concentration of suspended sediment above which fish resources are damaged and below which they are unaffected is not sharply defined (Gibbons 1982). Unfortunately, little information is available on suspended sediment, and much of it is poorly documented. Many of the life-cycle phases and requirements of salmonids can be affected by suspended sediment; however, intermittent additions of sediment are natural and are thought to have few detrimental effects on fish. Continuous additions may directly influence feeding and indirectly affect critical parts of the life cycle (table 5). Sediment can be produced from almost any recreational activity in uplands and transported to instream locations. Sediment can also affect angling time and success. Phillips (1971) stated that fishing success declines when suspended sediment exceeds 25 mg/liter and may cease when concentrations are greater than 100 mg/liter. Recent studies concerning the effects of sedimentation on rearing fish have indicated seasonal differences ranging from 1500 mg/liter to over 30 000 mg/liter before damage occurs (Noggle 1978). Thus, the intermittent additions of suspended sediment generally affect recreational angling and not necessarily the fish.

Water quality, bedload sediment.--Excessive amounts of fine sediment deposited in streams can reduce aquatic insect populations and diversity, available living space for fish, and survival of incubating embryos. The findings by Gibbons and Salo (1973) and Reiser and Bjornn (1979) show that: sediment can fill gravel interstices, thereby reducing intergravel and intragravel water flow; deposited sediment can physically prevent emergence of fry; and bedload sediment can reduce food resources by creating unfavorable substrates for the production of periphyton and aquatic invertebrates. Research shows the lethal effects of bedload sediment are most pronounced while the embryos are incubating in the gravel. Recreational activities can add sediment to streams by direct trampling of streambanks and, secondarily, by affecting upland soils (table 5). Through the use of riparian management strips, streambank stability can be improved, and upland sediments can be prevented from entering the stream channel.

Water quality, temperature.--Water temperature is a major determinant for salmonid production (table 5). Riparian vegetation directly influences water temperature by providing shade in summer and an insulating effect in winter. Recreational activities can remove this riparian vegetation.

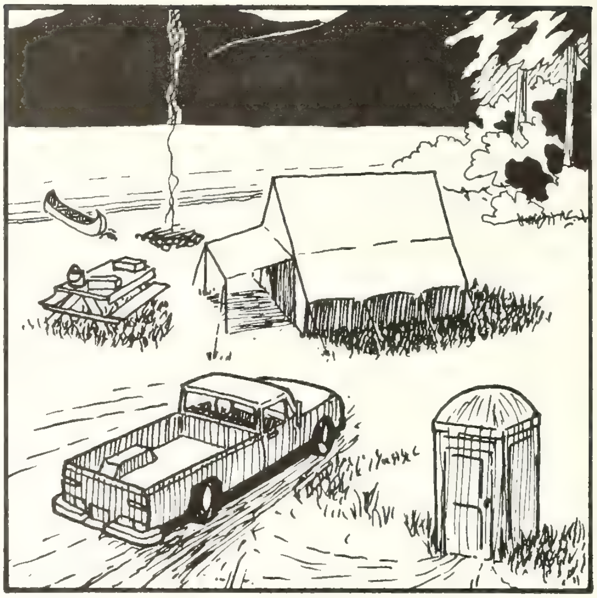
Water quality, dissolved oxygen.--Adequate dissolved oxygen is important to salmonids during all phases of their life cycle. Amount of dissolved oxygen is normally near saturation; recreational activities can, however, decrease these amounts by adding organic waste to slow-moving water. In general, the effects of recreation on dissolved oxygen levels is minor. Other effects would become critical before recreational activities would cause significantly low amounts of dissolved oxygen.

Water quality, fecal coliform bacteria.--Water pollution is generally measured in terms of bacterial count and index of coliform bacteria, which reflects the degree of animal (including human) waste. The occurrence of coliform bacteria in water may sometimes be associated with recreational activities. The introduction of coliform bacteria affects dissolved oxygen by increasing biological oxygen demand. Through proper siting and treating of human waste (and pack/riding stock waste), possible additions are then limited to bathing or swimming. The addition of fecal coliform bacteria from these uncontrollable sources should be minor.

Water quality, chemicals.--Bathing and washing soaps, herbicides, and insecticides are the principal recreational contaminators of water. Of these, herbicides and insecticides are of most concern. Spraying chemicals at campsites to control vegetation and insects can inadvertently result in their entering the water systems. Even low concentrations can drastically affect spawning and rearing success. Chemical additions to streams should not occur as a regular result of recreational activities. Norris and others (1983) thoroughly discussed these effects.

Barriers.--Stream barriers can provide both valuable rearing habitat and migration blocks to anadromous fish. The probability of recreational pursuits creating barriers preventing fish migration is slight, but if they occur, barriers can be critical.

Debris.—Large organic debris is an important habitat component of anadromous fish streams. It serves to: control waterflow, shape the stream channel, provide cover, form pools and riffles, trap and hold bedload sediment, increase habitat diversity, and provide substrate for biological activities of stream organisms (Meehan and others 1977). Swimmers, boaters, anglers, and others sometimes remove debris. Removal of large quantities can result in as much as an 80-percent reduction in anadromous fish populations (Elliott and Hubartt 1978), but such removal would rarely be a result of recreation. Debris removal by recreationists is primarily localized and should have minor effects on the total fish population of any stream.



EFFECTS OF MANAGEMENT ON RECREATION

Three classes of management actions or decisions are: recreation management, fishery management, and timber management. When possible effects of existing and potential recreational uses on anadromous fish habitat are evaluated, the influences of these actions must also be considered. In particular, planners and managers must be alert for possible effects outside of the recreation system itself (such as road construction) that may cause a chain reaction, ultimately changing the nature of recreational opportunities and future activities.

RECREATION MANAGEMENT

Certain decisions and actions of recreation managers may have implications for one or more aspects of fish habitat. Two basic types of actions are Recreation Opportunity Spectrum (ROS) class designation and management of ROS factors.

ROS is a model that helps to clarify relations among recreational settings, activities, and experiences (Brown and others 1978, Buist and Hoots 1982, Clark and Stankey 1979a, Clark 1982). The assumption underlying the ROS is that quality is best assured by providing diverse opportunities. The ROS recognizes that opportunities sought by recreationists range from easily accessible, highly developed areas with modern conveniences to undeveloped areas in remote locations (certain wilderness designations). Within each of the general types of settings, a variety of activities, such as fishing, camping, and hiking, is possible.

A recreation opportunity setting is defined as the combination of social, physical, biological, and managerial conditions that give perceived value to a place. It is distinguished by varying conditions ranging from modern to primitive, or as Nash (1973) phrased it, "from the paved to the primeval." The ROS includes six factors that influence recreational behavior and have significance to management. A more detailed description of these six factors may be found in Clark and Stankey (1979a), but briefly they are:

- Access into and within the area, with degree of difficulty associated with access and the permitted means of conveyance.

- The extent to which other nonrecreation resource uses (such as timber harvest, anadromous fishery management, and mining) are compatible (from the user's perspective) with various outdoor recreational activities.

- Onsite management--the extent, visibility, and complexity of modification, including the use of exotic vegetation, landscaping, traffic barriers, and facilities (tables, toilets, water supplies).

- Social interaction--the relative intensity of use per unit area, including the amount of intergroup contact and the space requirements associated with different opportunities.

- Level of regimentation--the nature, extent, and degree of control over recreational use exercised by management.

- Amount and degree of visitor effects acceptable in different opportunities (as perceived by users).

An example of how these factors can be combined to create a range of settings is shown in figure 7. Each of these factors is characterized by a range of conditions. For example, access ranges from areas where mechanical access on wide, paved highways is appropriate to areas without trails where only foot travel is permitted. Similarly, social interaction varies from high-density use (where it is appropriate and expected, such as in some modern campgrounds) to places of maximum solitude. The appropriateness of these conditions varies along the spectrum. Well-developed roads and large numbers of people with frequent contact between parties are not appropriate in wilderness, although they can be in places like beaches, near an urban area, or in highly developed campgrounds.

A recreation opportunity setting is created by specific combinations of these factors in a particular place. Alternative combinations lead to different opportunity settings, providing many options to recreationists.

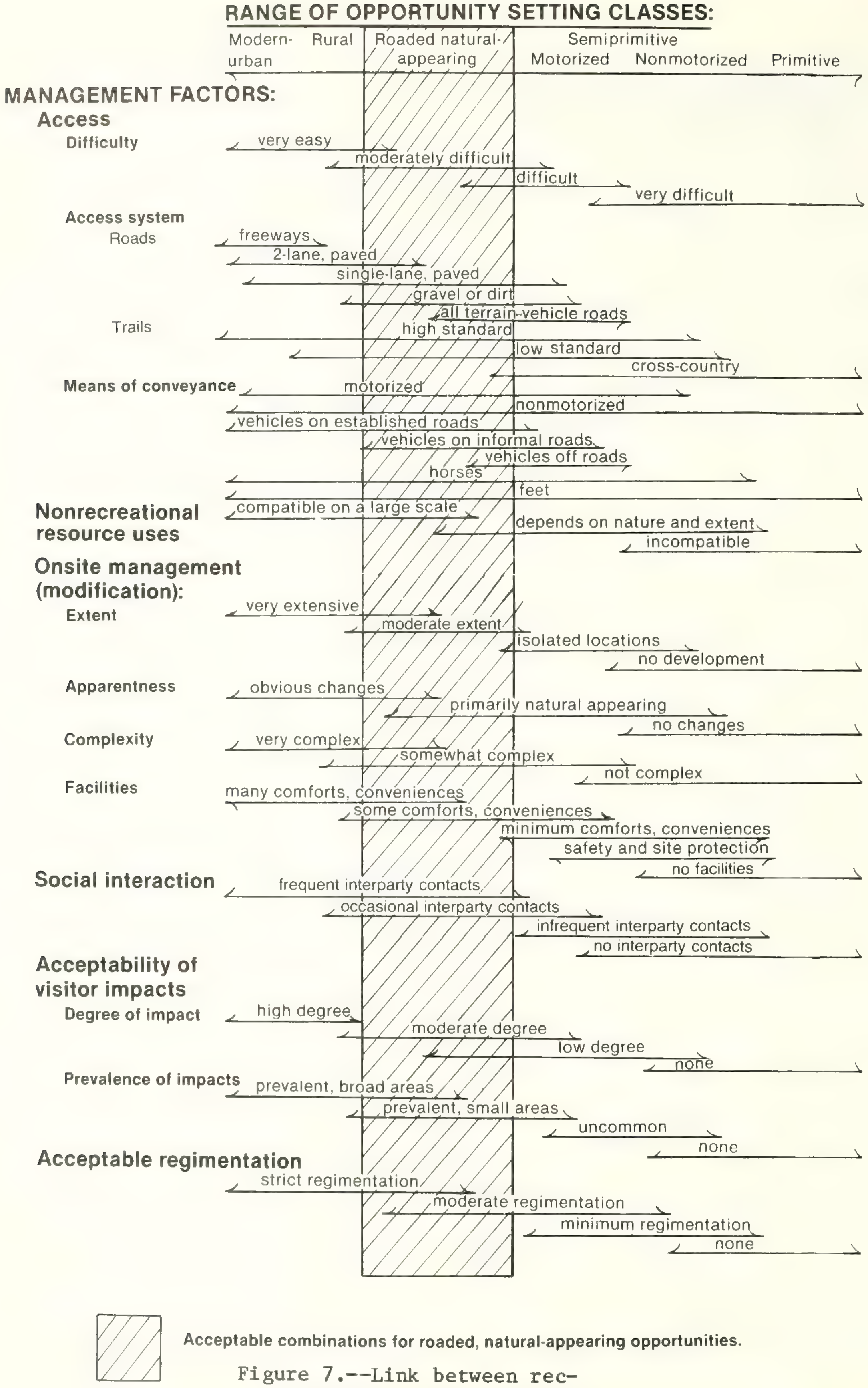


Figure 7.--Link between recreationists and opportunities (from Lucas and others 1984).

A recreation opportunity setting is also composed of other natural features in addition to the six factors. Land-form types, vegetation, scenery, water (lakes and streams), wildlife, and fish are all important elements of recreation environments; they influence where people go and the kinds of activities that are possible. No intrinsic quality of these other natural features suggests the appropriate type of recreation opportunity setting, however. Any of the opportunity types are as possible and appropriate in mountainous areas as they are in desert settings. Greatest diversity would be assured if the full spectrum of opportunity types (modern to primitive) could be found across the range of environmental settings.

The nature of participation in recreational activities depends on the place in which it occurs (Cheek and others 1976). Thus, natural features (terrain, rivers, lakes) will influence the activities that are possible. The combination of these environmental settings and opportunity types determines the range of recreational activities in a specific area.

The ROS assists resource planning and management by helping to integrate and coordinate recreation with other resource uses and management activities. The ROS can be applied to all kinds of land-use planning and resource management and is not only for recreation managers. Many of the factors defining recreational opportunity settings (access and use of other resources, for example) are traditionally the responsibility of other disciplines and functions (such as timber management and engineering). Coordination between different areas is necessary to insure that appropriate management objectives are stated (and achieved) and to help point out potential conflicts and compatibilities among resources (Brown and others 1978, Clark and Stankey 1979a).

ROS class designation.--Defining an ROS class in an area will not affect fish habitat until the area is used recreationally. Defining and managing by ROS class, however, may set in motion a chain of events that may affect the fishery. After classes are designated, management standards will be determined that are consistent with recreation goals. Presuming this all occurs according to plan, some general conclusions can be made about the relation between ROS class and anadromous fish habitat.

The modern-urban class is characterized by concentrated use, many facilities, paved roads, and diverse nonprimitive activities. Locating a modern-urban setting (such as in a developed campground) on or near fish habitat can have major implications for the fishery. Locally, substantial loss of vegetation, soil compaction, loss of streambank stability, and even some changes in the stream channel (depending on size) can occur. Water quality may be affected when sanitation facilities are near streams or when insecticides or herbicides are used to control insects or brush. Use of horses or vehicles along or in streams may accelerate deterioration of banks and substrate.

At the other end of the spectrum, the primitive class is characterized by light (dispersed) use, lack of most comfort and safety facilities, and primitive means of transportation (foot or horse). Effects on fish habitat can range from none to minor, where use is infrequent (although as Cole (1979) points out, initial light use may result in most of the effect on soils and vegetation), to substantial, where use is more concentrated--such as along trails or at popular campsites.

ROS management factors.--Whether the factors helping to define the ROS are managed in an attempt to influence recreational use, or are managed for some other purpose, recreational use can be affected in nature and extent in specific areas (see fig. 7).

Access decisions will have major implications for the nature and extent of recreational use and subsequent effects on fish habitat. The location and design of logging roads and recreation trails will in a large part determine use patterns and amounts. If trail routes are at some distance from the water, effects on fish habitat will be minimized. Where stream crossings occur, disruption is likely and will be related to the nature and extent of the activities. Mode of access--foot, horse, vehicle--may also have different effects. Clark and Stankey (1979a) have indicated that managers can control type of access to anadromous fish streams and the means of conveyance allowed. Both access elements can vary along the spectrum from easy to extremely difficult. Design and management standards are important in defining the range of access. Often, topography and the type of vegetation define the range of possible access. Thus, managers are able to use a combination of natural features, design and maintenance standards, and regulations to maintain the amount of access into any given area. New roads or facilities should be designed and constructed to minimize disturbance. A review of road-construction practices for the protection of salmonid habitat has been presented by Yee and Roelofs (1980). The condition of the access road will have a strong bearing on the recreational pressure (including angling) exerted on the stream. As the distance increases from access points on anadromous fish streams, recreation density (including anglers) will decrease.

Nonrecreational resource uses in an area will influence the type of recreation that occurs.

Onsite modifications provided for recreation--such as boat launches and docks, restrooms, tables, fireplaces, and shelters--can substantially affect the distribution of recreational uses. Some people will find these conveniences disruptive, and they will look for less developed places. People desiring such conveniences will congregate there.

Other management factors.--Other recreation-management actions, such as the spraying of herbicides or insecticides, may also have some significance for fish habitat. Removal of dangerous trees in areas of intense recreation can lead to loss of overhead and instream cover and increased soil and bank instability, which can reduce food sources, cover, and shade for fish.

FISHERY MANAGEMENT

Fishery managers can affect recreation by habitat manipulation, chemical treatment, biological manipulation, and regulatory action. Various specific actions under each of these categories follow:

- Habitat manipulation
  - Installing fish ladders
  - Planting riparian vegetation
  - Removing instream debris
  - Adding instream organic debris and boulders
  - Modifying barriers (removing beaver dams, blasting falls)
  - Creating pools (blasting)
  - Adding spawning gravel
  - Removing fine sediment
  - Creating spawning channels
  - Building weirs and dams
- Chemical treatments
  - Fertilizing lakes
  - Eradicating fish (for example with rotenone)
  - Controlling plants
- Biological manipulation
  - Stocking from hatcheries ("put-and-take" stocking or to build up populations)
  - Installing instream incubation boxes
  - Removing unwanted fish populations (predators or competitors)
  - Introducing exotic species
- Regulatory actions
  - Setting bag limits
  - Setting size limits
  - Setting license limits (rationing)
  - Limiting seasons
  - Regulating gear
  - Limiting access (boat launches)

Habitat-manipulation projects may either decrease or increase recreational use. When roads are necessary for project access and left open for public use, they can increase use. While the project is underway (from 1 week to several months), recreational activities occurring near the project might be disrupted. Structures that result from projects may also have some effect on recreational activities. Regulations in the west coast States usually prohibit fishing, but not other activities, near such structures. The sight of structures may cause people to go elsewhere along the stream, which may expand the area affected by recreational use. Creation of pools, with their potential for swimming, bathing, and fishing, may attract people to an otherwise undesirable site.

Chemical treatments are most often used for lakes, although streams are occasionally treated. For example, in the California Golden Trout Wilderness, brown trout are being eradicated so that the less competitive species--the golden trout--can dominate their native habitats. This type of action may also affect recreational use.

Biological manipulation may result in permanent structures, such as migration barriers, that can affect recreation. Stocking influences only where and how much fishing occurs.

Regulatory actions for fishery management are generally limited to effects on fishing, with the exception of such actions as controlling access and building launching ramps.

TIMBER MANAGEMENT

Timber-management activities can have major effects on recreational use. Conversion of a roadless natural area to one with a road changes the recreational setting. Roadless areas receive little use, and it is dispersed over broad areas. Roads and clearings, particularly those near water, provide opportunities for concentrated use. As changes are made, redistribution of use likely will occur (see fig. 4). When roads are located near riparian areas, recreational activities have an increased effect on anadromous fish habitat. Where temporary or long-term logging camps are located (such as in Southeast Alaska), recreational use will increase in nearby areas.

MANAGING RECREATION TO PROTECT THE FISHERY

MANAGEMENT OBJECTIVES

Defining clear management objectives in advance of any action is a prerequisite to effective solutions (Brown 1979, Clark and Stankey 1979a, Roggenbuck and Schreyer 1977). Management without such objectives can only be reactive. Objectives based on perception are appropriate if assumptions are made explicit (Clark 1982, Thomas 1979). Coordination among resource uses is critical, and recreational objectives must be integrated with fishery- and timber-management objectives.

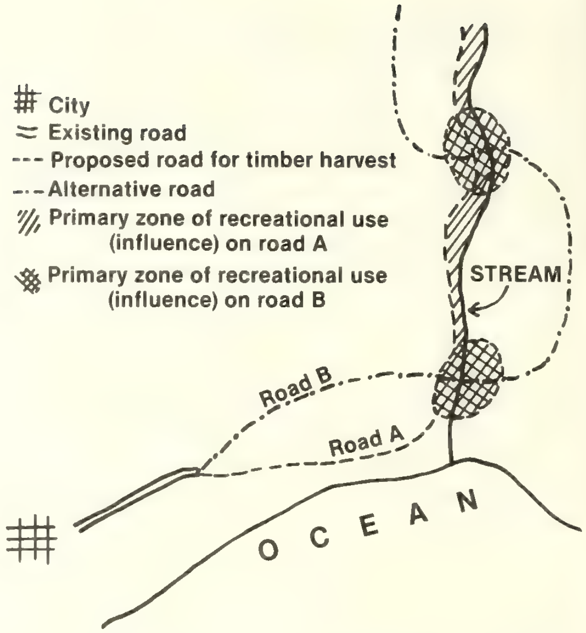
ROS FACTORS

Management of ROS factors based on objectives as stated above has important effects on recreation. Because the ROS focuses on specific features of the physical, social, and managerial setting, it simplifies analysis of how proposed management actions will alter the nature of a specific recreational opportunity.

For example, the decision to develop an area for timber harvest has the obvious consequence of changing the amount and obtrusiveness of nonrecreational resource uses, but logging also may improve access to an area. Improved access can lead to higher use and greater demand for facilities. Many of these changes can be anticipated by management. The ROS provides management with a simple, graphic way of portraying these anticipated outcomes and evaluating whether they are appropriate or desirable.

The design and location of roads and trails near rivers will influence the probability and distribution of recreational use, and the resulting resource effects. A road following a river is more likely to have detrimental effects on the fishery than is a road built farther away (fig. 8).

Anticipating and precluding use in certain areas is generally easier than controlling use after a problem has occurred. Careful selection of sites for roads, trails, camps, and other facilities can influence use patterns (Beardsley and Wagar 1971, Settergren 1977). Usually, campgrounds should be located away from riparian areas or in areas of least disruption (Kuska 1977). For the fishery, encouraging recreational use along lake shores rather than along stream banks is preferred because lakes are less likely to be disturbed by recreational activities.



City
Existing road
Proposed road for timber harvest
Alternative road
Primary zone of recreational use (influence) on road A
Primary zone of recreational use (influence) on road B
STREAM
Road B
Road A
OCEAN

Figure 8.--Potential effects of alternative road locations on recreational use.

ACTIVITY MANAGEMENT

Managing activities directly is often advisable when adverse effects from recreation occur or are expected to occur. Regulating and prohibiting certain activities may help solve problems if users understand and agree with the rationale behind the restrictions (Clark and others 1971). Managers cannot control all use just by regulating fishing because some people using the area may not fish and would not be affected by actions such as creel limits and gear restrictions.

EDUCATION

Educating users might help prevent or control problems. If recreationists are aware of how they may influence the fishery, they might avoid practices endangering fish habitat.

RESTING OF SITES

Allowing sites to rest may reduce the effects of recreational use. Such a policy may spread the effects over a broader area, however (Cole 1979); most of the changes in vegetation result from initial light use and not from continuous and increased recreation. Furthermore, recovery from detrimental effects may take many years or may never occur if users do not comply with the restriction (Cole and Ranz 1983). Other alternatives should be seriously considered before adopting this approach.

Problems can be solved more effectively if a variety of strategies is used. Preventing a problem through planning is easier than controlling one after it occurs (Magill 1977).

CONCLUSIONS

We have described various ways that recreational use and anadromous fish habitat affect each other. Knowledge about these interactions is scarce; hence the conclusions we make in this paper must be regarded as best guesses.

The riparian zone tends to be recreationally more important than other areas. People are drawn to water and, as a consequence, may do things that adversely affect fish production. Riparian areas are managed for a variety of human values, and this management affects the nature and extent of recreational uses.

We believe recreation will usually have an insignificant effect on fish habitat. Any recreational use of upland and riparian areas will have some usually minor effects compared to the influence of roads and logging. The biggest recreational effect is harvesting of fish populations, not destruction of habitat. The effects of recreational fishing throughout the range of anadromous fish in western North America are so variable, however, that they must be evaluated locally. Managers should pay particular attention to vegetative changes along long reaches of important rivers. Healthy vegetation appears to play a critical role in fish-habitat productivity and is one of the first habitat components affected by recreational use.

Establishing management objectives before any onsite action is essential to effective recreation management. Making explicit decisions will help anticipate influences from all uses, including recreation. The ROS helps planners and managers explicitly state their assumptions, management objectives, and presumed consequences to recreational opportunities of management alternatives. A clear understanding of the rationale behind options will help in their application. Identifying problems and issues, and setting management objectives have often been overlooked in resource-management planning (Stankey 1980). The ROS will not make decisions; it does allow planners and managers to test assumptions, and it provides the possible consequences of various options. Stating management objectives (for example, what to provide, how, where, when, and for whom) helps in successfully using the ROS. Defining limits of acceptable change to anadromous fish habitat will simplify monitoring and evaluating changes that occur (Stankey and others, in press). Bjornn and others (1980), Gibbons (1982), and Heller and others (1983) have discussed methods for determining risks to anadromous fish habitat as a result of management activities.

Planners and managers responsible for anadromous fish habitat must have a method for analyzing management actions and their consequences, to be included in making multiresource decisions. Thus, past management actions and results can be used to shape future actions. Recreation is interdependent with other resource uses; if the nature and extent of effects from recreational use are to be understood, these links must be examined.

Roads can be provided specifically for recreation or for other resource uses. Recreational use often increases dramatically when roads are open for public use. Increased road use in sensitive locations may result in unacceptable effects on fish production. Unanticipated effects are less likely to occur when all of the resources are considered during planning.

Fishery managers must be careful that their actions do not detract from recreational opportunities and use. A balance between user and resource must: maintain the natural capacity of the stream to produce wild fish; retain management options for the future; answer demands for recreation, including fish and fishing; consider success of stocked versus wild fish; and preserve esthetic values that are part of the specialist's experience. We should beware of using projections of historical trends as a sole basis for planning, because this can lead to managing for intensive fisheries and to dependence on artificial production. Considering all users equally will provide the means for continuation and use of recreational resources. Managers must understand the demand for fishing, catching fish, and maintaining fish habitat as part of the total recreational experience an area can provide.

We have shown how little documentation exists about the interrelations between recreational uses and the anadromous fishery. Some of the topics that should be studied are summarized below.

Aitcheson and others (1977), Clark and Lucas (1978), and Kuska (1977), pointed out the need for objective baseline information on the supply and use of rivers for a variety of recreational pursuits. In addition, site conditions must be documented to provide a basis for monitoring and evaluating recreational effects on fish habitat. An adequate data base will assist specific studies of both the social and biological systems. Baseline information is needed for regions, watersheds, and specific sites.

For individual river systems, we need to determine the significance of effects from various kinds of recreational uses on components of fish habitat. How these effects differ by river and ecosystem types should also be evaluated. Studies to determine the effects of intensive versus dispersed recreation should be conducted through an experimental design that evaluates alternative recreational use patterns for micro- and macrosites. Strategies to reduce or ameliorate unacceptable effects could be tested.

Studies are also required to separate the effects of recreational use from those associated with roads, logging, grazing, and mining. Determining the conditions under which various uses interact on the habitat of anadromous fish requires multifunctional, multisystems research.

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Processing Data From Soil Assessment Surveys With the Computer Program SOILS

John W. Hazard, Jeralyn Snellgrove, and J. Michael Geist

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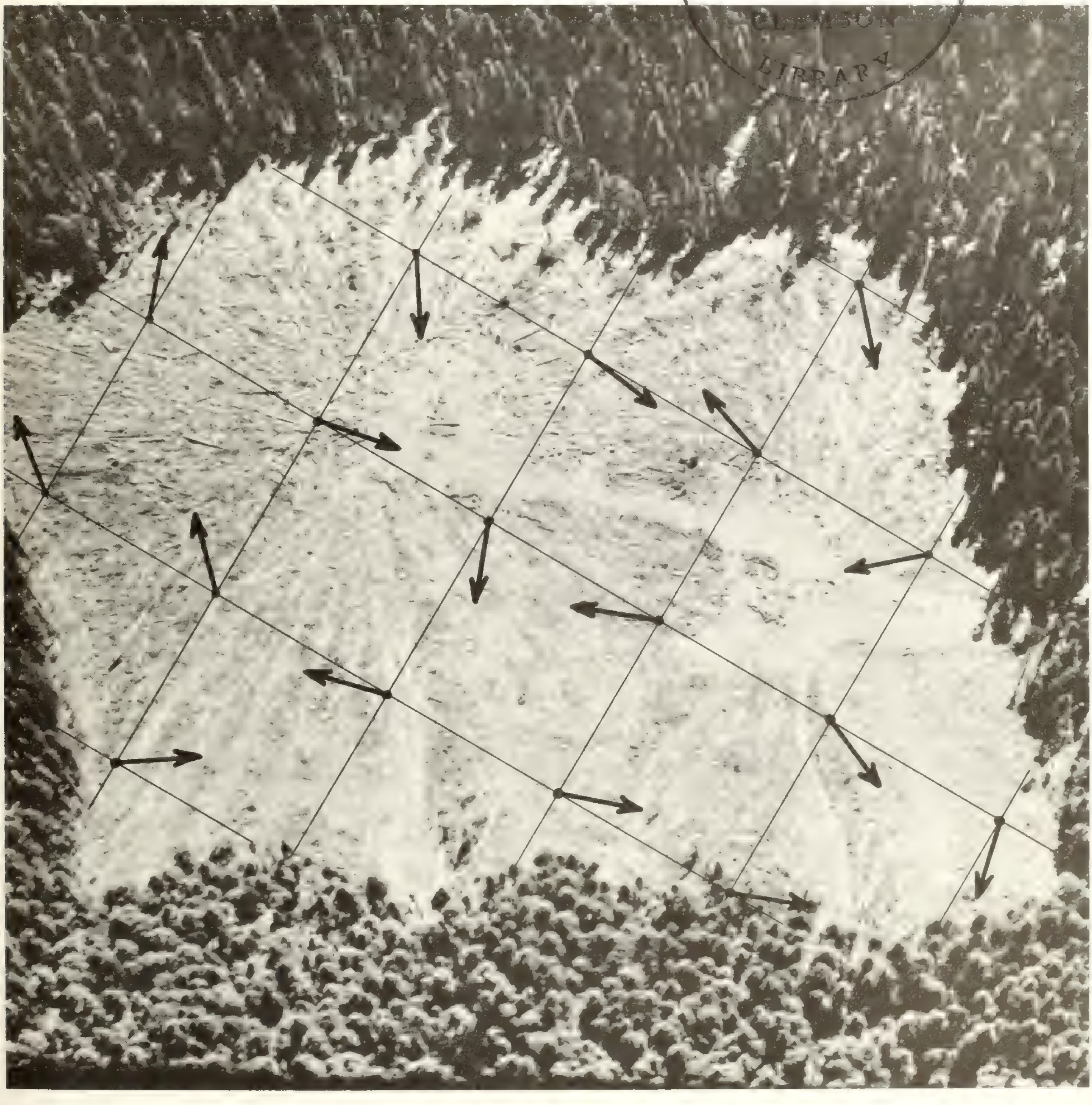

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Abstract

Hazard, John W.; Snellgrove, Jeralyn; Geist, J. Michael. Processing data from soil assessment surveys with the computer program SOILS. Gen. Tech. Rep. PNW-179. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985.** 26 p.

Program SOILS processes data from soil assessment surveys following a design adopted by the Pacific Northwest Region of the USDA Forest Service. It accepts measurements from line transects and associated soil subsamples and generates estimates of the percentages of the sampled area falling in each soil condition class. Total disturbance is calculated by combining certain detrimental soil condition classes. Variances and confidence intervals of the percentage of each class are computed. Summary or preliminary estimates may be inserted into the program for computing sample sizes to help in planning future surveys.

A summary of the soil survey design for the Pacific Northwest Region, the estimation procedures, and the sample size calculation procedures are also provided.

Keywords: Soil surveys, computer programs/programming, sampling designs.

Contents

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Introduction

Soil assessment surveys are designed to estimate soil conditions at specified points in time, such as before and after management activities. The reason might be to determine if soil productivity has been impacted by management activities.

The Resources Planning Act of 1974 and the National Forest Management Act of 1976 require National Forest managers to monitor and evaluate resources (including soils) affected by management activities and to attempt to predict the consequences of management decisions in relation to planning alternatives.

The Pacific Northwest Region (Region 6) of the National Forest System has issued a directive which addresses policies and standards for maintaining land productivity under multiple use and sustained yield principles. The directive addresses the monitoring of mass wasting, soil displacement, deposition, puddling, compaction, and erosion.

Region 6 soil assessment surveys are required to generate estimates of total damage and soil condition classes—undisturbed, displaced, deposited, puddled, compacted, eroded, and "other" soil condition classes—with indices of the reliability of these estimates. In addition, statistical tests are desired to determine if the realized level of detrimental influence from management activities for each survey situation exceeds standards for the Region.

The objective of this paper is to provide instructions for and an example of processing data from surveys conducted according to the soil assessment survey design used by Region 6,[1] with a computer program called SOILS. In addition, a brief description of the design, the estimation procedures, and the sample size calculations are provided.

The program SOILS was written to process soil assessment surveys of Region 6. It accepts measurements from transects and associated subsamples and generates estimates of the percentages of the area sampled (activity unit) in each of the condition classes. Total disturbance is calculated by combining the detrimental condition classes (displaced, puddled, eroded, and compacted). Variances and confidence intervals for the percentages of disturbance in each class are computed. In addition, preliminary or summary estimates can be inserted into the computations to provide sample size approximations to help in planning future surveys.

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[1] Detailed instructions appear in Howes, S. W.; Hazard, J. W.; Geist, J. M. Guidelines for sampling some physical conditions of surface soils. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Range and Watershed Management; 1983.

The Pacific Northwest Region Design

The soil assessment survey design for Region 6 is a systematic sample located on a square grid. Surface soil characteristics are measured continuously along each transect radiating from the grid intersections. Subsurface characteristics such as compaction are measured at fixed points along the transects. The transects are randomly oriented around the respective grid points. They can vary in length and there can be one or more per grid point.[2]

The point subsamples along the transects are located at equal intervals, but the number of subsamples can vary; 10 and 20 points have been most frequently used with 100-foot transects.[3] The program SOILS is currently restricted to a maximum of 20 points per transect.

There are two types of observed values for each transect: the length of each line falling in the respective surface soil condition classes (data type 1 records) and the soil compaction reading of each point subsample (data type 2 records).

The individual soil compaction reading is compared with the standard for compaction (which is set independent of the sample) and is classified into compacted or uncompacted categories within each of the surface soil conditions for each transect. The length of each line transect in the surface soil conditions is combined with the summary of the compaction data to form the adjusted percentages for each transect, as follows:

Data from type 1 and 2 records of each transect are summarized into a 2 × 7 matrix. The row entries of the matrix represent the compacted and uncompacted classes, and column entries represent the seven surface soil condition classes. The entries are formed by proportioning the percentages of line length in each soil condition class into compacted and uncompacted categories, based on the percentage of the point subsamples in each condition class that were compacted or uncompacted. The number of point subsamples involved in each class is also represented in this matrix.

The estimates for the activity unit totals are formed by combining the adjusted transect percentages as outlined in appendix A. The procedures for sample size calculations appear in appendix B.

Program SOILS

This section presents the details and explanations for data setup, selection of soil assessment statistical analyses, and results. An example is provided to illustrate these details.

The computer program is written in FORTRAN V and meets the current ANSI standards (FSH 6609.33). It is assumed that users have a basic knowledge of FORTRAN format codes, and of accessing the Fort Collins Computer Center UNIVAC where the program is on file. For information contact Jeralyn Snellgrove, Forestry Sciences Laboratory, P.O. Box 3890, Portland, OR 97208 (503-231-2098).

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[2] The existing version of SOILS handles only one transect per grid point. Certain spatial distributions of soil conditions may warrant more than one transect.

[3] 1 foot = 0.3048 meter. Bulk density readings appear as they are commonly measured in grams per cubic centimeter. All other units are in English.

Input Control Records

Computer program SOILS may require up to three types of control records each time an activity area is processed. Control type 1 is the title record and control type 2 is the options record. Both are required. Control type 3 is required only when compaction readings are taken outside the designated activity area to compute the Region 6 standard.

The following are detailed formats and descriptions of the input control records. Each control record format identifies the "variable name" used in the program to reference that particular piece of information, the number and location of "columns" reserved for the respective information, the FORTRAN "format" in one of three types (A = alphanumeric, FX.X = floating point numeric, and IX = integer numeric characters), and a description of the "information" being recorded. These specifications must be followed rigorously.

Control type 1 — title record.—Every activity unit being processed requires a title record. It can be used for providing additional introductory information or instructions for interpreting the results that will follow.

Variable name	Columns	Format	Information
LABEL	1-80	A	Description of activity unit being analyzed.

Control type 2 — options record.—The options record provides the specifications of the analysis problem for the activity unit being processed. It includes the following specifications: To print all data entries in labeled fields; the type of compaction measurements to be processed (air permeameter and/or bulk density, or no compaction measurements); the method of computing the standard for compaction (either calculated from an outside area or given by the soils resource scientist responsible for that analysis); the option to compute confidence intervals for estimates of all condition classes; and the option to compute sample sizes.

When the options to compute confidence intervals and sample sizes are chosen, the desired probability levels (two-tailed) are required to be specified in the options record. The margins of error and the condition class of interest must also be specified when sample sizes are calculated. A second iteration of the sample size calculation is optional.

Variable name[4]	Columns	Format	Information
NRDGS	1	I1	Determines type of data to be analyzed. Blank or zero = process both air permeameter and bulk density readings. Use only when all transects contain both types of readings. Otherwise, process each type independently in separate runs. 1 = process air permeameter only. 2 = process bulk density only. 3 = compaction measurements omitted (that is, surface measurements only).[5]
	2	1X	Blank.
LIST	3	I1	Option to print data. Blank = don't list. 1 = list.
	4	1X	Blank.

---

[4] All variables on the control records and the data records are to be justified on the right.

[5] Option 3 was included to allow summarization of surface measurements only. This option is recommended when surface measurements are made without classification error and soil core measurements are not necessary.

Variable name	Columns	Format	Information
NCMPBD	5-6	I2	Standard for bulk density given or to be computed. Blank or zero = standard for bulk density given in columns 8-11. n = number of control type 3 records (used for computing standard for bulk density).
	7	1X	Blank.
STDBD	8-11	F4.3	Standard for bulk density (if given, columns 13-25 will be blank).
	12	1X	Blank.
NREPS	13	I1	Specifies the number of times the activity unit is to be analyzed using different standards for compaction. If specified, columns 8-11 must be blank. Maximum of three possible standards. Blank or 1 = unit will be processed one time. Columns 15-17 must contain the percentage increase in bulk density. 2 = unit will be processed two times. Columns 15-17 and 19-21 must contain percentages. 3 = unit will be processed three times. Columns 15-17, 19-21, and 23-25 must contain percentages.
	14	1X	Blank.

Variable name	Columns	Format	Information
STDPCT(1)	15-17	F3.2	Relative (percentage) increase in bulk density. Used to compute the absolute standard for compaction in the initial analysis (that is, 15, 20, 30).
	18	1X	Blank.
STDPCT(2)	19-21	F3.2	Percentage increase in bulk density. Used to compute the absolute standard for compaction in the second analysis (optional).
	22	1X	Blank.
STDPCT(3)	23-25	F3.2	Percentage increase in bulk density. Used to compute the absolute standard for compaction in the third analysis (optional).
	26	1X	Blank.
NOPT3	27	I1	Option for calculating confidence intervals. Blank or zero = no confidence intervals desired. (Columns 28-30 will also be blank.) 1 = compute confidence intervals. (Columns 28-30 must be filled.)
PRBLVL(4)	28-30	F3.2	Probability level (two-tailed) used in confidence interval calculation (must be 80, 90, or 95).
	31	1X	Blank.

Variable name	Columns	Format	Information
NOPT2	32	I1	Option for computing sample size table(s). (Refer to appendix B for further explanations.) Blank or zero = no computation desired. (Columns 34-63 will also be blank.) 1 = alternative 1 (relative margin of error). (Columns 35-37 and columns 44-46 must also be filled. Columns 38-43 and 47-52 are optional for this alternative.) 2 = alternative 2 (absolute margin of error). (Columns 35-37 and columns 53-55 must also be filled. Columns 38-43 and 56-61 are optional for this alternative.) 3 = alternative 3 (relative and absolute margins of error). Columns 35-37, 44-46, and 53-55 must also be filled. Columns 38-43, 47-52, 56-61 are optional for this alternative.)
	33	1X	Blank.
ICLASS	34	I1	Class of interest used in sample size calculation (additional classes of interest require separate runs): 1 = visual compaction; 2 = displaced; 3 = deposition; 4 = puddled; 5 = eroded; 6 = undisturbed; 7 = other; 8 = total disturbance.

Variable name	Columns	Format	Information
PRBLVL(1)	35-37	F3.2	First probability level used in sample size calculation for either alternative 1 or 2, appendix B (three or fewer probability levels can be specified, levels must be 80, 90, or 95).
PRBLVL(2)	38-40	F3.2	Second probability level (80, 90, or 95) used in sample size calculations (optional).
PRBLVL(3)	41-43	F3.2	Third probability level (80, 90, or 95) used in sample size calculation (optional).
E1	44-46	F3.2	First margin of error value used in alternative 1 of sample size calculation, appendix B (three or fewer margin of error values can be specified).
E2	47-49	F3.2	Second margin of error value used in alternative 1 of sample size calculation. (optional).
E3	50-52	F3.2	Third margin of error value used in alternative 1 of sample size calculation (optional).
E4	53-55	F3.2	First margin of error value used in alternative 2 of sample size calculation, appendix B (three or fewer margin of error values can be specified).
E5	56-58	F3.2	Second margin of error value used in alternative 2 of sample size calculation (optional).
E6	59-61	F3.2	Third margin of error value used in alternative 2 of sample size calculation (optional).
	62	1X	Blank.
ITERS	63	I1	Option to print first or second iteration of sample size calculation. 1 = print first iteration only (d.f. = ∞). 2 = print second iteration only (d.f. = n−1 where n is calculated in first iteration).

Control type 3 — outside area record (optional).—Control type 3 records are used to input compaction measurements taken outside the activity unit. These readings are taken on a representative sample of the undisturbed soil condition surrounding the activity unit. The mean reading is calculated and multiplied by the desired percent increase in bulk density, specified in STDPCT(1), STDPCT(2), or STDPCT(3) of control type 2 record, to produce the standard for compaction. This procedure is designed to be used only for bulk density measurements of compaction.

Variable name	Columns	Format	Information
BD	1-80	20F4.3	Contains bulk density readings from outside the area. Used when computing the standard for bulk density. Each record can contain up to 20 readings. Readings are recorded continuously on records. The number of records used is the value of NCMPBD (columns 5-6) on control type 2.

Data Records

Data records follow the control records. Data records are organized by transect number and by condition class within transects. The program SOILS currently processes a maximum of 40 transects per activity area. There are two types of data records. Type 1 records contain the line length surface measurements in each condition class by transect. Type 2 records contain the compaction measurements at subsample points along the transect. A maximum of 12 air permeameter readings can be recorded (one or two at a point) per record, and six bulk density measurements (one at a point) per record. Additional measurements appear in subsequent data records.

Data type 1 — surface measurements.—

Variable name	Columns	Format	Information
NCT	1	I1	First record of a transect, enter value of 1.
NTR	2-3	I2	Transect number.
	4-5	2X	Blank.
A(1)	6-8	F3.0	Length of line that falls in visual compaction condition class (to nearest foot).
A(2)	9-11	F3.0	Length of line that falls in displaced condition class (to nearest foot).
	12-15	4X	Blank.
A(3)	16-18	F3.0	Length of line that falls in deposition condition class (to nearest foot).
A(4)	19-21	F3.0	Length of line that falls in puddled condition class (to nearest foot).
	22-25	4X	Blank.
A(5)	26-28	F3.0	Length of line that falls in eroded condition class (to nearest foot).
A(6)	29-31	F3.0	Length of line that falls in undisturbed condition class (to nearest foot).
	32-35	4X	Blank.
A(7)	36-38	F3.0	Length of line that falls in other condition class (to nearest foot).
A(8)	39-41	F3.0	Total length of transect line (to nearest foot).

Data type 2 — compaction measurements.—

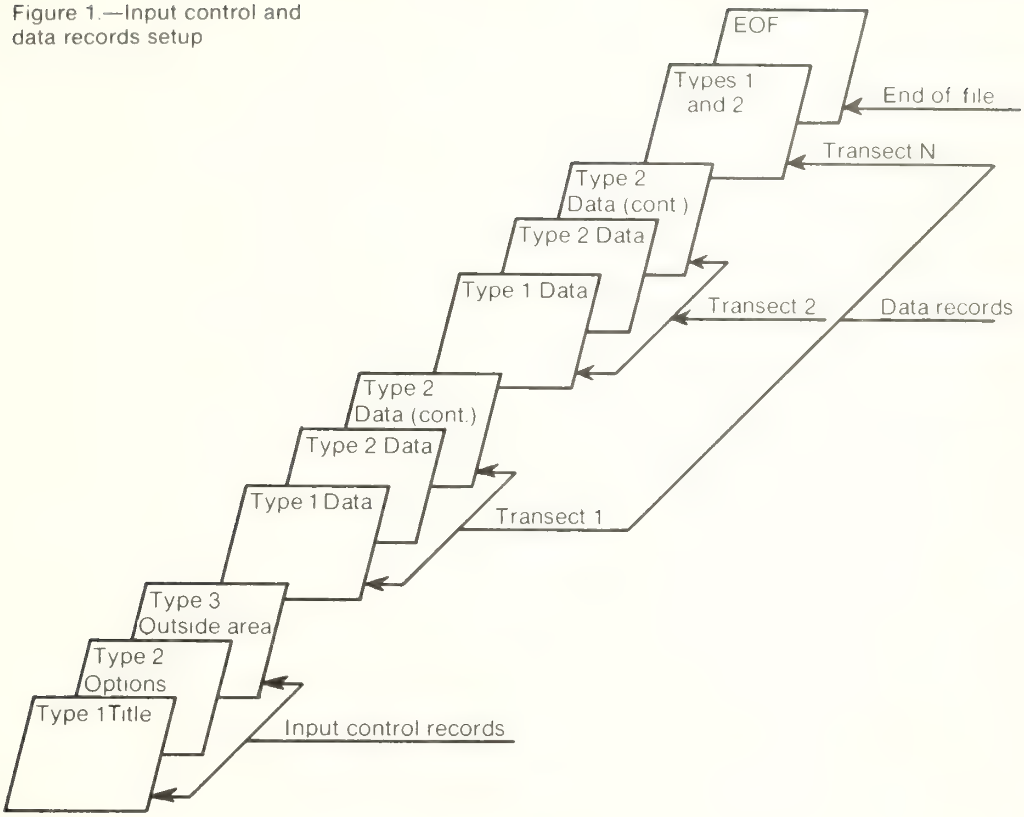
Variable name	Columns	Format	Information
NCT	1	I1	Second data record of a transect, enter value of 2.
NTR	2-3	I2	Transect number.
NCC	4	I1	Condition class: 1 = visual compaction; 2 = displaced; 3 = deposition; 4 = puddled; 5 = eroded; 6 = undisturbed; 7 = other.
NCONT	5	I1	Condition class record number. Data are grouped by condition class within transects. If more than the maximum number of readings for a record occur for a condition class, more than one record will be necessary. Additional records must be numbered sequentially. Enter value of 1, 2, 3, or 4 to indicate the record number of a specified condition class. For example, a condition class containing seven bulk density readings would require two records to obtain the seven readings; thus, the value of NCONT (the first record) for the first six readings would be 1, and NCONT would be 2 on the second record, which would contain the seventh reading.
A(1)	6-8	F3.1	Air permeameter reading. Other instrument readings of compaction can be recorded in the place of permeameter readings; however, different standards would have to be introduced into the program.
A(2)	9-11	F3.1	Second air permeameter reading taken at same point location. If only one air permeameter reading is taken at each point, leave second air permeameter reading field blank.

Variable name	Columns	Format	Information
B(1)	12-15	F4.3	Bulk density reading.
A(3)	16-18	F3.1	Air permeameter reading.
A(4)	19-21	F3.1	Second air permeameter reading.
B(2)	22-25	F4.3	Bulk density reading.
A(5)	26-28	F3.1	Air permeameter reading.
A(6)	29-31	F3.1	Second air permeameter reading.
B(3)	32-35	F4.3	Bulk density reading.
A(7)	36-38	F3.1	Air permeameter reading.
A(8)	39-41	F3.1	Second air permeameter reading.
B(4)	42-45	F4.3	Bulk density reading.
A(9)	46-48	F3.1	Air permeameter reading.
A(10)	49-51	F3.1	Second air permeameter reading.
B(5)	52-55	F4.3	Bulk density reading.
A(11)	56-58	F3.1	Air permeameter reading.
A(12)	59-61	F3.1	Second air permeameter reading.
B(6)	62-65	F4.3	Bulk density reading.

Record Order

Figure 1 illustrates the setup for a typical analysis. As shown, the input control records come first. They consist of a title record; an options record; and, if necessary, an outside area record(s). Immediately following the input control records are the data records. They are grouped by transects and contain type 1 and type 2 records. A type 1 data record is always the first record of a transect; the remaining records of that transect are type 2. If only surface measurements are being analyzed, the data records are all type 1.

Figure 1.—Input control and data records setup



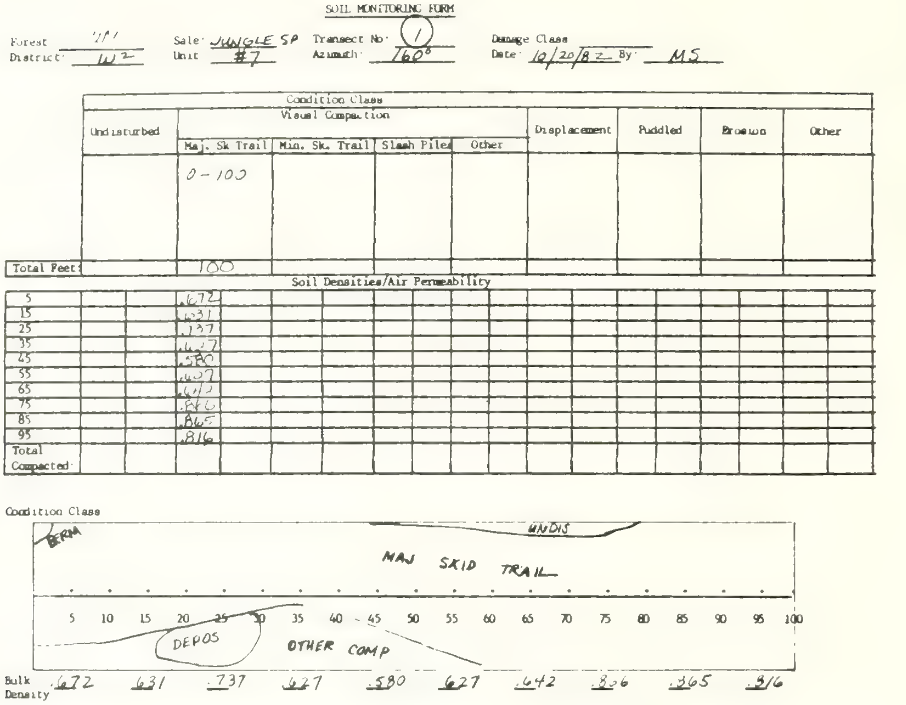
FCCC set-up to execute a run:

```
@RUN
@ASG,A SLS6*SOILS.
@XQT SLS6*SOILS.PRG-M
@ADD SLS6*SOILS.DATA-M
@FIN
```

Input Record Forms

Figure 2 represents the field sheets for transect 1 and transect 2 of the activity unit used in the following example. On this particular form the visual compaction condition class is broken down into four groups (major skid trail, minimum skid trail, slash piles, and other). For data entry purposes these four groups should be combined and the line lengths added together to get only one length for the visual compaction class; that is, in transect 2, the line length for visual compaction would be 45 feet. Also note that this form does not include a separate column for deposition. As shown in transect 2, measurements falling into the deposition condition class were recorded under "other." During the data entry process, however, care must be taken to ensure that these measurements are recorded under the correct condition class.

Figure 2.—Field forms with bulk density compaction readings for transect 1 (top) and transect 2 (bottom).



SOIL MONITORING FORM

Forest: AM
District: W2
Sale: JUNGLE SP
Unit: #7
Transect No: 1
Azimuth: 160°
Damage Class:
Date: 10/20/82 By: MS

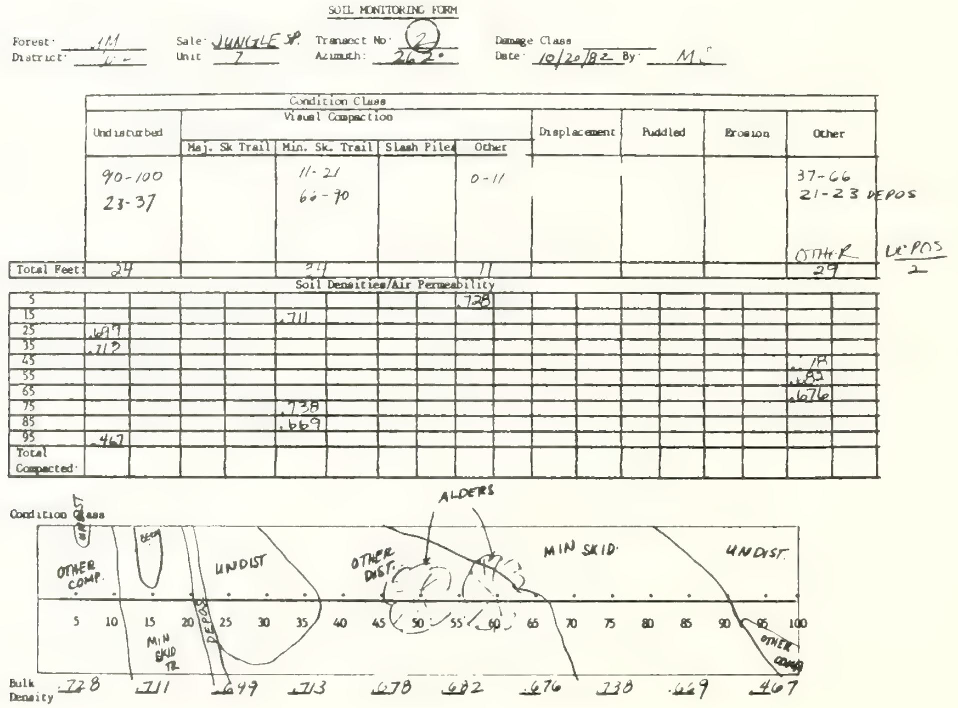
	Condition Class								
	Undisturbed	Visual Compaction				Displacement	Puddled	Erosion	Other
		Maj. Sk Trail	Min. Sk. Trail	Slash Piles	Other				
		0-100							
Total Feet:		100							

Soil Densities/Air Permeability

5		.672							
15		.631							
25		.737							
35		.627							
45		.580							
55		.627							
65		.642							
75		.846							
85		.865							
95		.816							
Total Compacted:									

Condition Class

Bulk Density .672 .631 .737 .627 .580 .627 .642 .846 .365 .316



SOIL MONITORING FORM

Forest: AM
District: W2
Sale: JUNGLE SP.
Unit: 7
Transect No: 2
Azimuth: 262°
Damage Class:
Date: 10/20/82 By: MS

	Condition Class								
	Undisturbed	Visual Compaction				Displacement	Puddled	Erosion	Other
		Maj. Sk Trail	Min. Sk. Trail	Slash Piles	Other				
	90-100 23-37		11-21 66-90		0-11				37-66 21-23 DEPOS OTHER
Total Feet:	24		24		11				29

DEPOS
2

Soil Densities/Air Permeability

5					.728				
15			.711						
25	.699								
35	.712								
45									.678
55									.682
65									.676
75			.738						
85			.669						
95	.467								
Total Compacted:									

Condition Class

Bulk Density .728 .711 .699 .713 .678 .682 .676 .738 .669 .467

Example

Figure 3 is the complete file which was read into program SOILS for the example. Umatilla National Forest, Jungle Springs unit. This particular activity unit contained bulk density compaction readings only. The "options record" specified the following: Only bulk density compaction readings will be processed (column 1 = 2); no listing of the data is desired (column 3 = blank); the standard for bulk density will be computed (columns 8-11 = blank) with data taken from an "outside area" which is recorded on two records (column 6 = 2); the area will be analyzed once (column 13 = 1 and columns 19-25 = blank); a 15-percent increase in bulk density is used for computing the standard for compaction (columns 15-17 = 15); confidence intervals will be computed (column 27 = 1) with a 90-percent probability level (columns 29-30 = 90); both absolute and relative sample size calculations are desired (column 32 = 3) with total disturbance being the condition class of interest (column 34 = 8); three probability levels (80, 90, and 95 percent), which will be used for all sample size calculations, are desired (columns 35-43 = 80, 90, 95); two margin of error values (20 and 10 percent) will be used in calculating the first (relative) sample size table (columns 44-49 = 20 and 10); the same two values will be used in the second (absolute) sample size calculations (columns 53-58 = 20 and 10); and the second iteration for the sample size calculations is to be printed (column 63 = 2).

There are two "outside area records" with 30 bulk density readings on the undisturbed condition. These readings begin with 0.545 g/cm^3 and end with 0.505 g/cm^3.

Transect 1 has three data records, one type 1 and two type 2 records. The type 1 data record for transect 1 contains 100 feet of visual compaction (on the field form (fig. 2) this condition is shown as a major skid trail); 100 also occurs in columns 39-41 indicating the total line length. There were 10 bulk density readings recorded on the two type 2 data records, beginning with 0.672 g/cm^3 and ending with 0.816 g/cm^3. The data records for the remaining 14 transects follow in order.

```
TITLE RECORD                  UMATILLA FOREST, JUNGLE SPRINGS UNIT
OPTIONS RECORD                2    2      1  15         1 90 3 8 80 90 95 20 10    20 10    2
OUTSIDE AREA RECORD            545 575 768 539 571 740 642 669 583 597 636 635 577 697 763 579 704 643 692 666
OUTSIDE AREA RECORD            676 665 641 656 643 594 620 618 565 505
TYPE 1 DATA RECORD            1 1  100                              100
TYPE 2 DATA RECORD            2 111       672       631       737       627       580       627
TYPE 2 DATA RECORD            2 112       642       866       865       816
TYPE 1 DATA RECORD            1 2   45         2           24      29100
TYPE 2 DATA RECORD            2 211       728       711       738       669
TYPE 2 DATA RECORD            2 261       699       713       467
TYPE 2 DATA RECORD            2 271       678       682       676
       .                      1 3   56                     44        100
       .                      2 311       681       702       687       573       671       654
       .                      2 361       603       687       532       536
      etc.                    1 4   45        10           10      35100
                              2 411      1003       739       716       779
                              2 431       690
                              2 461       603
                              2 471       805       843       511       670
                              1 5   40                     26      34100
                              2 511       780       755       735       760
                              2 561       638       605       730
                              2 571       706       671       654
                              1 6   69        25                    6100
                              2 611       849       697       772       948       893       820
                              2 612       731
                              2 631       752       814
                              2 671       710
                              1 7   68        14                   18100
                              2 711       699       649       610       734       793       747
                              2 712       841
                              2 731       688
                              2 771       603       688
                              1 8   96         4                     100
                              2 811       848       730       862       683       696       665
                              2 812       695       737       676
                              2 831       626
                              1 9   87        13                     100
                              2 911       654       630       707       717       672       689
                              2 912       710       739
                              2 931       587       546
                              110   37        23                   40100
                              21011       799       627       674       624
                              21031       734       712
                              21071       678       674       524       587
                              111   73                     12      15100
                              21111       710       709       668       523       663       643
                              21112       747       692       705
                              21171       677
                              112   89        11                     100
                              21211       737       563       704       806       745       706
                              21212       725       789       976
                              21231       620
                              113   56        19                   25100
                              21311       823       681       642       748       779       678
                              21331       656       548
                              21371       742       558
                              114   94         6                     100
                              21411       691       673       767       627       683       750
                              21412       775       646       642
                              21431       617
                              115   79                             21100
                              21511       633       702       666       789       782       739
                              21512       618       679
                              21571       621       745
                              EOF
```

Figure 3.—Input control records and data records with bulk density compaction readings.

Output Summaries

The data appearing in figure 3 are input into the program SOILS, and three output summaries are produced: figure 4, output summary for each transect; figure 5, output summary for the activity unit; and figure 6, sample size calculations. The estimation procedures for these summaries appear in appendixes A and B.

Figure 4 presents the 2 × 7 matrices (described previously) for each transect. There are 15 of these matrices corresponding to the 15 transects taken in the Jungle Springs unit. Note that the 100 feet of visual compaction has been partitioned into "compacted" and "uncompacted" classes based on the bulk density readings in data type 2 records. Refer to figure 5; the average bulk density of the 30 readings, taken on the outside area, was 0.633 g/cm^3. The relative standard percent was 15 percent. Therefore, the bulk density standard is $1.15 \times 0.633 = 0.728$ g/cm^3. The 10 bulk density readings, noted on transect 1 on the input data type 2 records, show that four were greater than 0.728 and six were equal to or less than 0.728. Thus, the partition of the 100 feet was 60/40 to the uncompacted/compacted classes. This process is repeated for each transect.

Figure 5 presents a summary of each transect for the activity unit. Definitions of which cells in the 2 × 7 matrix are combined to form the transect summary appear in appendix A. The mean and variance are computed for all transects in the activity unit for each condition class. Note that the Jungle Springs unit had an estimated 34.53 percent damaged, 65.47 percent undisturbed, 8.47 percent deposition, and 14.87 percent other.

Confidence intervals are computed for the mean percentages of each condition class. These appear at the bottom of figure 5. Recall that the "options record" designated a 90-percent confidence interval.

Sample sizes are calculated for the conditions designated in the "options record." These are done for planning purposes and for determining whether the activity unit met an acceptable level of disturbance. Additional explanations of these calculations appear in the reference in footnote 1 and in appendix B.

```
          UMATILLA FOREST, JUNGLE SPRINGS UNIT


                                                BULK DENSITY    - TRANSECT  1.
                                                  LINE LENGTH PERCENTAGES

                  UNDISTURBED     DISPLACED      DEPOSITION      PUDDLED     ERODED     VISUAL COMP.     OTHER
COMPACTED             .0( 0.)        .0( 0.)         .0( 0.)        .0( 0.)     .0( 0.)     40.0( 4.)      .0( 0.)
UNCOMP.               .0( 0.)        .0( 0.)         .0( 0.)        .0( 0.)     .0( 0.)     60.0( 6.)      .0( 0.)

                                                BULK DENSITY    - TRANSECT  2.
                                                  LINE LENGTH PERCENTAGES

                  UNDISTURBED     DISPLACED      DEPOSITION      PUDDLED     ERODED     VISUAL COMP.     OTHER
COMPACTED             .0( 0.)        .0( 0.)         .0( 0.)        .0( 0.)     .0( 0.)     11.2( 1.)      .0( 0.)
UNCOMP.             24.0( 3.)        .0( 0.)        2.0( 0.)        .0( 0.)     .0( 0.)     33.8( 3.)    29.0( 3.)

                                                BULK DENSITY    - TRANSECT  3.
                                                  LINE LENGTH PERCENTAGES

                  UNDISTURBED     DISPLACED      DEPOSITION      PUDDLED     ERODED     VISUAL COMP.     OTHER
COMPACTED             .0( 0.)        .0( 0.)         .0( 0.)        .0( 0.)     .0( 0.)       .0( 0.)      .0( 0.)
UNCOMP.             44.0( 4.)        .0( 0.)         .0( 0.)        .0( 0.)     .0( 0.)     56.0( 6.)      .0( 0.)

                                                BULK DENSITY    - TRANSECT  4.
                                                  LINE LENGTH PERCENTAGES

                  UNDISTURBED     DISPLACED      DEPOSITION      PUDDLED     ERODED     VISUAL COMP.     OTHER
COMPACTED             .0( 0.)        .0( 0.)         .0( 0.)        .0( 0.)     .0( 0.)     33.7( 3.)    17.5( 2.)
UNCOMP.             10.0( 1.)        .0( 0.)       10.0( 1.)        .0( 0.)     .0( 0.)     11.3( 1.)    17.5( 2.)

                                                BULK DENSITY    - TRANSECT  5.
                                                  LINE LENGTH PERCENTAGES

                  UNDISTURBED     DISPLACED      DEPOSITION      PUDDLED     ERODED     VISUAL COMP.     OTHER
COMPACTED            8.7( 1.)        .0( 0.)         .0( 0.)        .0( 0.)     .0( 0.)     40.0( 4.)      .0( 0.)
UNCOMP.             17.3( 2.)        .0( 0.)         .0( 0.)        .0( 0.)     .0( 0.)       .0( 0.)    34.0( 3.)

                                                BULK DENSITY    - TRANSECT  6.
                                                  LINE LENGTH PERCENTAGES

                  UNDISTURBED     DISPLACED      DEPOSITION      PUDDLED     ERODED     VISUAL COMP.     OTHER
COMPACTED             .0( 0.)        .0( 0.)       25.0( 2.)        .0( 0.)     .0( 0.)     59.1( 6.)      .0( 0.)
UNCOMP.               .0( 0.)        .0( 0.)         .0( 0.)        .0( 0.)     .0( 0.)      9.9( 1.)     6.0( 1.)

                                                BULK DENSITY    - TRANSECT  7.
                                                  LINE LENGTH PERCENTAGES

                  UNDISTURBED     DISPLACED      DEPOSITION      PUDDLED     ERODED     VISUAL COMP.     OTHER
COMPACTED             .0( 0.)        .0( 0.)         .0( 0.)        .0( 0.)     .0( 0.)     38.9( 4.)      .0( 0.)
UNCOMP.               .0( 0.)        .0( 0.)       14.0( 1.)        .0( 0.)     .0( 0.)     29.1( 3.)    18.0( 2.)
```

Figure 4.—Output summary for each transect.

```
                                         BULK DENSITY   - TRANSECT  8.
                                          LINE LENGTH PERCENTAGES

              UNDISTURBED    DISPLACED    DEPOSITION    PUDDLED    ERODED    VISUAL COMP.    OTHER
COMPACTED         .0( 0.)      .0( 0.)       .0( 0.)    .0( 0.)   .0( 0.)     42.7( 4.)     .0( 0.)
UNCOMP.           .0( 0.)      .0( 0.)      4.0( 1.)    .0( 0.)   .0( 0.)     53.3( 5.)     .0( 0.)

                                         BULK DENSITY   - TRANSECT  9.
                                          LINE LENGTH PERCENTAGES

              UNDISTURBED    DISPLACED    DEPOSITION    PUDDLED    ERODED    VISUAL COMP.    OTHER
COMPACTED         .0( 0.)      .0( 0.)       .0( 0.)    .0( 0.)   .0( 0.)     10.9( 1.)     .0( 0.)
UNCOMP.           .0( 0.)      .0( 0.)     13.0( 2.)    .0( 0.)   .0( 0.)     76.1( 7.)     .0( 0.)

                                         BULK DENSITY   - TRANSECT 10.
                                          LINE LENGTH PERCENTAGES

              UNDISTURBED    DISPLACED    DEPOSITION    PUDDLED    ERODED    VISUAL COMP.    OTHER
COMPACTED         .0( 0.)      .0( 0.)     11.5( 1.)    .0( 0.)   .0( 0.)      9.2( 1.)     .0( 0.)
UNCOMP.           .0( 0.)      .0( 0.)     11.5( 1.)    .0( 0.)   .0( 0.)     27.8( 3.)   40.0( 4.)

                                         BULK DENSITY   - TRANSECT 11.
                                          LINE LENGTH PERCENTAGES

              UNDISTURBED    DISPLACED    DEPOSITION    PUDDLED    ERODED    VISUAL COMP.    OTHER
COMPACTED         .0( 0.)      .0( 0.)       .0( 0.)    .0( 0.)   .0( 0.)      8.1( 1.)     .0( 0.)
UNCOMP.         12.0( 0.)      .0( 0.)       .0( 0.)    .0( 0.)   .0( 0.)     64.9( 8.)   15.0( 1.)

                                         BULK DENSITY   - TRANSECT 12.
                                          LINE LENGTH PERCENTAGES

              UNDISTURBED    DISPLACED    DEPOSITION    PUDDLED    ERODED    VISUAL COMP.    OTHER
COMPACTED         .0( 0.)      .0( 0.)       .0( 0.)    .0( 0.)   .0( 0.)     49.4( 5.)     .0( 0.)
UNCOMP.           .0( 0.)      .0( 0.)     11.0( 1.)    .0( 0.)   .0( 0.)     39.6( 4.)     .0( 0.)

                                         BULK DENSITY   - TRANSECT 13.
                                          LINE LENGTH PERCENTAGES

              UNDISTURBED    DISPLACED    DEPOSITION    PUDDLED    ERODED    VISUAL COMP.    OTHER
COMPACTED         .0( 0.)      .0( 0.)       .0( 0.)    .0( 0.)   .0( 0.)     28.0( 3.)   12.5( 1.)
UNCOMP.           .0( 0.)      .0( 0.)     19.0( 2.)    .0( 0.)   .0( 0.)     28.0( 3.)   12.5( 1.)

                                         BULK DENSITY   - TRANSECT 14.
                                          LINE LENGTH PERCENTAGES

              UNDISTURBED    DISPLACED    DEPOSITION    PUDDLED    ERODED    VISUAL COMP.    OTHER
COMPACTED         .0( 0.)      .0( 0.)       .0( 0.)    .0( 0.)   .0( 0.)     31.3( 3.)     .0( 0.)
UNCOMP.           .0( 0.)      .0( 0.)      6.0( 1.)    .0( 0.)   .0( 0.)     62.7( 6.)     .0( 0.)

                                         BULK DENSITY   - TRANSECT 15.
                                          LINE LENGTH PERCENTAGES

              UNDISTURBED    DISPLACED    DEPOSITION    PUDDLED    ERODED    VISUAL COMP.    OTHER
COMPACTED         .0( 0.)      .0( 0.)       .0( 0.)    .0( 0.)   .0( 0.)     29.6( 3.)   10.5( 1.)
UNCOMP.           .0( 0.)      .0( 0.)       .0( 0.)    .0( 0.)   .0( 0.)     49.4( 5.)   10.5( 1.)
```

Figure 4.—Output summary for each transect (continued).

```
                 UMATILLA FOREST, JUNGLE SPRINGS UNIT

                                                   BULK DENSITY   READINGS
                                                  CONDITION CLASSES (PI.)
                                                         (PERCENT)

                                                UNDISTURBED MEAN B.D. = 0.633

                                        DAMAGE LEVEL (UNDIST.MEAN X 1.15) B.D. = 0.728
            TRANSECT   TOTAL
             NUMBER   DAMAGE*   UNDISTURBED   COMPACTED   DISPLACED   DEPOSITION   PUDDLED   ERODED   OTHER
                 1.       40.        60.          40.          0.          0.        0.       0.       0.
                 2.       11.        89.          11.          0.          2.        0.       0.      29.
                 3.        0.       100.           0.          0.          0.        0.       0.       0.
                 4.       51.        49.          51.          0.         10.        0.       0.      35.
                 5.       49.        51.          49.          0.          0.        0.       0.      34.
                 6.       84.        16.          84.          0.         25.        0.       0.       6.
                 7.       39.        61.          39.          0.         14.        0.       0.      18.
                 8.       43.        57.          43.          0.          4.        0.       0.       0.
                 9.       11.        89.          11.          0.         13.        0.       0.       0.
                10.       21.        79.          21.          0.         23.        0.       0.      40.
                11.        8.        92.           8.          0.          0.        0.       0.      15.
                12.       49.        51.          49.          0.         11.        0.       0.       0.
                13.       41.        59.          41.          0.         19.        0.       0.      25.
                14.       31.        69.          31.          0.          6.        0.       0.       0.
                15.       40.        60.          40.          0.          0.        0.       0.      21.
         P.. (MEAN) =     34.53      65.47        34.53          .00        8.47       .00      .00    14.87
V(PI.) (VARIANCE) =      466.93     466.93       466.93          .00       77.27       .00      .00   225.55

*TOTAL DAMAGE = 100-(UNCOMPACTED VISUAL COMPACTION + UNCOMPACTED DEPOSITION + UNCOMPACTED UNDISTURBED + UNCOMPACTED OTHER)


                                                CONFIDENCE INTERVALS (.90)

                                             TOTAL DAMAGE =  34.53 +OR-  9.83
                                              UNDISTURBED =  65.47 +OR-  9.83
                                                COMPACTED =  34.53 +OR-  9.83
                                                DISPLACED =    .00 +OR-   .00
                                               DEPOSITION =   8.47 +OR-  4.00
                                                  PUDDLED =    .00 +OR-   .00
                                                   ERODED =    .00 +OR-   .00
                                                    OTHER =  14.87 +OR-  6.83
```

Figure 5.—Output summary for the activity unit.

```
                        * * * * * * * * ITERATION 2 * * * * * * * *
                        SAMPLE SIZE CALCULATIONS BASED ON SPECIFIED
                          CONFIDENCE INTERVALS ON TOTAL DAMAGE

                            VARIANCE =466.93   MEAN = 34.53


                                  MARGIN OF ERROR (RELATIVE)

                             .20             .10             .00
                          ***************************************
                          *             *             *             *
                    0.80  *   17.50     *     65.77   *       .00   *
                          *             *             *             *
PROBABILITY               ***************************************
  LEVEL                   *             *             *             *
                    0.90  *   28.49     *    108.03   *       .00   *
                          *             *             *             *
                          ***************************************
                          *             *             *             *
                    0.95  *   40.34     *    150.43   *       .00   *
                          *             *             *             *
                          ***************************************
```

```
                        * * * * * * * * ITERATION 2 * * * * * * * *
                        SAMPLE SIZE CALCULATIONS BASED ON SPECIFIED
                             MINIMUM STANDARD ON TOTAL DAMAGE

                            VARIANCE =466.93   MEAN = 34.53


                                     STANDARD (ABSOLUTE)

                            20.              10.             0.
                          ***************************************
                          *             *             *             *
                    0.80  *    5.93     *      7.35   *       .00   *
                          *             *             *             *
PROBABILITY               ***************************************
  LEVEL                   *             *             *             *
                    0.90  *    8.98     *      6.62   *       .00   *
                          *             *             *             *
                          ***************************************
                          *             *             *             *
                    0.95  *   11.76     *     14.37   *       .00   *
                          *             *             *             *
                          ***************************************
```

Figure 6.—Sample size calculations.

Appendix A
Estimation Procedures

The estimation procedures not documented in Howes and others (see footnote 1, p. 1) are presented here.

Symbology.—Let l_{ij} be the length of the i^{th} transect observed in the j^{th} soil condition class.

Soil condition classes are defined as:

$j =$ 1 visual compaction (roads, heavy skid trails, etc.);
2 displaced;
3 deposited;
4 puddled;
5 eroded;
6 undisturbed; and
7 other.

The values $l_{i1}, \ldots, l_{i7}$ are the lengths in classes 1-7 for the same i^{th} transect,

and $\sum_{j=1}^{7} l_{ij} = l_i$ is the total length of the i^{th} line. The length of transects in a soil survey should be kept constant.

Let d_{ijk} be the bulk density or another variable of interest for the k^{th} core (subsample) in the j^{th} class on the i^{th} transect. The point subsample may be at intervals of 5 or 10 feet, so that $k = 1, \ldots, 10$, or 20.

Define d_o as the established average undisturbed bulk density (from an independent source or "outside area records"), and $d_s = 1.15d_o$ as the damage level standard, provided by the Region 6 directive mentioned earlier.

Logic.—Compare d_{ijk} with d_s; if

$d_{ijk} > d_s$, set $d_{ijk} = 1$ implies the d_{ijk}th point is compacted, or

$d_{ijk} \leq d_s$, set $d_{ijk} = 0$ implies the point is uncompacted.

$d_{ij} = \sum_{k=1}^{n_{ij}} d_{ijk}$ is the number of cores compacted falling in the j^{th} condition class on the i^{th} transect,

n_{ij} is the total number of cores in the j^{th} condition class on the i^{th} transect;

$d_{ij\cdot} = \sum_{k=1}^{n_{ij}} \frac{d_{ijk}}{n_{ij}}$ is the proportion of points in the j^{th} condition class of the i^{th} transect which are compacted (a dot subscript symbolizes that entries have been averaged over the replaced subscript);

$1 - d_{ij\cdot}$ = the compliment percentage of points in the ij^{th} transect-condition class not compacted;

$p_{ij\cdot} = \frac{l_{ij}}{l_i} (d_{ij\cdot})$ is the percentage of the i^{th} transect in the j^{th} condition class which is damaged by compaction; and

$q_{ij\cdot} = \frac{l_{ij}}{l_i} (1 - d_{ij\cdot})$ is the percentage of the i^{th} transect in the j^{th} condition class which is not compacted.

The estimates for the activity unit are:

$$\hat{P} \text{ undisturbed} = \sum_{i=1}^{n} (q_{i1\cdot} + q_{i3\cdot} + q_{i6\cdot} + q_{i7\cdot})/n;$$

where n is the number of transects in the sample. The entry $q_{i1\cdot}$ is the proportion of the visual compaction condition class classified on the i^{th} transect which is adjusted into undisturbed on the basis of the proportion of compaction points that were uncompacted. Similarly, $q_{i3\cdot}$, $q_{i6\cdot}$, and $q_{i7\cdot}$ are the proportions of "deposition," "undisturbed," and "other" classes that were uncompacted as was determined from the subsample of cores.

$$\hat{P}\ \text{compacted} = \sum_{i=1}^{n} \sum_{j=1}^{7} p_{ij}./n;$$

$$\hat{P}\ \text{displaced} = \sum_{i=1}^{n} (p_{i2}. + q_{i2}.)/n = \sum_{i=1}^{n} \frac{1_{i2}}{1_i};$$

$$\hat{P}\ \text{deposited} = \sum_{i=1}^{n} (p_{i3}. + q_{i3}.)/n = \sum_{i=1}^{n} \frac{1_{i3}}{1_i};$$

$$\hat{P}\ \text{puddled} = \sum_{i=1}^{n} (p_{i4}. + q_{i4}.)/n = \sum_{i=1}^{n} \frac{1_{i4}}{1_i};$$

$$\hat{P}\ \text{eroded} = \sum_{i=1}^{n} (p_{i5}. + q_{i5}.)/n = \sum_{i=1}^{n} \frac{1_{i5}}{1_i};$$

$$\hat{P}\ \text{other} = \sum_{i=1}^{n} (p_{i7}. + q_{i7}.)/n = \sum_{i=1}^{n} \frac{1_{i7}}{1_i};$$

$$\hat{P}\ \text{total disturbance} = 1 - \sum_{i=1}^{n} (q_{il}. + q_{i3}. + q_{i6}. + q_{i7}.)/n;$$

$$\text{variance} = \sum_{i=1}^{n} \frac{(p_i. - p..)^2}{n-1}\ \text{(see footnote 1, p. 1);}$$

where $p_i.$ is the proportion from the i^{th} transect in the j^{th} class constructed with the p_{ij}'s and q_{ij}'s defined above, and $p..$ is the average of the $p_i.$ for all transects in the sample.

For example, the $v(\hat{P}$ undisturbed) is

$$v(\hat{P}) = \sum_{i=1}^{n} \frac{(p_i. - p..)^2}{n-1};$$

but

$$\hat{P}\ \text{undisturbed} = \sum_{i=1}^{n} (q_{i1}. + q_{i3}. + q_{i6}. + q_{i7}.)/n$$

$$= \sum_{i=1}^{n} (p_i.)/n\ \text{if}\ p_i. = q_{i1}. + q_{i3}. + q_{i6}. + q_{i7}.$$

$$= p..$$

Therefore,

$$v(\hat{P}) = v(\hat{p}..) = \sum_{i=1}^{n} \frac{((q_{i1}. + q_{i3}. + q_{i6}. + q_{i7}.) - \hat{P})^2}{n-1}.$$

Appendix B
Sample Size Calculations

The systematic sample is processed as a random sample. Sample sizes will be conservative because the true variance of a systematic sample of soil disturbance will generally be less than that estimated by random sampling.

Two alternative sample size calculations exist, and the choice depends on the specific objective of the survey.

Alternative 1.—The objective is to estimate P (the proportion of the activity area in a specific soil condition class) at a specified level of precision; that is, P is within plus or minus a fixed percentage of the true value, unless a stated probability of error occurs. For example, if an estimation of the true value ± 10 percent at the 95-percent confidence probability is desired, the sample size is approximated as

$$n \doteq \frac{t^2 s^2}{(0.10\hat{P})^2} \; ;$$

where:

in the first iteration, t is the Student's t value for ∞ degrees of freedom for $\alpha = 0.05$ (1 − the confidence probability). If a second iteration is desired, a new t value with the first iteration n–1 (where n has been incremented to the next whole number) degrees of freedom will be used.

s^2 is the variance among transect values for the soil condition class on which the sample size will be controlled.

$\hat{P}$ is the estimate of the proportion of that soil condition class.

A table (for either iteration 1 or iteration 2) is printed with three levels of the confidence probability ($1 - \alpha$) and three levels of the specified relative margin of error (for example, ± 10 percent in the previous example).

Alternative 2.—The objective in alternative 2 is to test whether $\hat{P} \geq P_o$, at a stated probability of significance. For example, frequently, a simple decision is desired of whether the resulting proportion of disturbance, $\hat{P}$, exceeds a standard P_o. If this is the objective then n is calculated as

$$n \doteq \frac{t^2 s^2}{(\hat{P} - P_o)^2} .$$

For example, based on the example from the Umatilla National Forest in the text, $\hat{P}$ (total damage) is expected to be 34.53 percent. The standard, P_o, is specified at 20 percent. With $t_{0.05} = 1.96$, $s^2 = 466.93$,

$$n \doteq 1.96^2(466.93)/(34.53-20)^2 = 8.5 \text{ transects.}$$

A second iteration produces n = 11.8; refer to figure 6 in the text.

If we use alternative 1 and set the margin of error to be ±20 percent of $\hat{P}$ at $\alpha = 0.05$, with $s^2 = 466.93$,

$$n \doteq 1.96^2(466.93)/(0.20(34.53))^2 = 37.6 \text{ transects.}$$

A second iteration produces n = 40.3; see figure 6.

Thus, how the results are applied in relation to the standards and decision criteria is important for the resulting sample size. The practical implications on budget requirements are obvious.

Two tables of sample sizes (for either iteration) were constructed. Refer to control type 2, the "options record" (p. 3). Note that in column 32 the decision of which table(s) to construct is made. Both tables have the capability of being 3 x 3 matrices (that is, three Student's t values with corresponding critical regions, and three margins of error expressed in either relative or absolute units).

*GPO 595 - 487 (19

Hazard, John W.; Snellgrove, Jeralyn; Geist, J. Michael. Processing data from soil assessment surveys with the computer program SOILS. Gen. Tech. Rep PNW-179. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985.** 26 p.

Program SOILS processes data from soil assessment surveys following a design adopted by the Pacific Northwest Region of the USDA Forest Service. It accepts measurements from line transects and associated soil subsamples and generates estimates of the percentages of the sampled area falling in each soil condition class Total disturbance is calculated by combining certain detrimental soil condition classes. Variances and confidence intervals of the percentage of each class are computed. Summary or preliminary estimates may be inserted into the program for computing sample sizes to help in planning future surveys.

A summary of the soil survey design for the Pacific Northwest Region, the estimation procedures, and the sample size calculation procedures are also provided.

Keywords: Soil surveys, computer programs/programming, sampling designs.

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FOREWORD

Forest and related resource management in mountainous areas of the western United States, Canada, and Alaska is severely restricted by unstable terrain that is susceptible to soil movement varying from surface creep to catastrophic landslides. Management practices that might trigger or increase such disturbance are increasingly subject to public scrutiny.

Land managment planning as required by the Resources Planning Act (RPA) (PL93-378), the National Forest Management Act (NFMA)(PL94-588), the Resource Conservation Act (RCA) (PL95-192) and other Federal and State laws requires that soil stability receive strong consideration in long-range plans. Accordingly, planners have a critical need for the best possible information on soil stability and risk of landslides, and potential impacts on other resources.

Much research and development work has been done in the West by public agencies, industry, and universities on the causes, effects, prevention, and impacts of soil movement. The largest project of this nature has been the USDA Forest Service's Interstation Soil Mass Movement Research Program which was begun in 1972. This effort is being conducted by three western Forest Service Experiment Stations (Pacific Southwest, Pacific Northwest, and Intermountain Forest and Range Experiment Stations) working in close cooperation with the western Regions of the Forest Service, the Bureau of Land Management, western States, universities, and others concerned with slope stability problems. Since the program began, more than 100 technical reports have been produced, and land managers and researchers have made significant progress in applying the information in the field. In February 1984 a workshop on "Slope stability: problems and solutions in forest management" was held at the Univeristy of Washington, Seattle, and was designed to give high-level administrators, decisionmakers, and planners a current perspective on the status of these research and administrative studies, key findings, and how new information is being applied.

Publication of the proceedings of this workshop accomplishes two primary purposes. The first is to bringing together in coherent form, and from as wide a range of experience as possible, information on resources and techniques useful to the land manager who must identify, assess, and mitigate the risk of soil mass movements from steep, forested terrain. The second is to define managerial risk and provide a forum for the expression by land managers of views on the concepts of risk in forest land management decisionmaking. Foremost among these views are the perceived needs, in terms of data and techniques, for effective risk assessment given current social and political constraints.

The concepts, techniques, and applications presented constitute some of the best and most successful approaches currently being applied by specialists and land management decisionmakers. They are, by no means, the only viable approaches to assessment and management of this difficult terrain. After all, there is no single "best approach" applicable under all conditions. Land managers are encouraged to consult soils, hydrology, and geotechnical specialists with specific local knowledge and experience for guidance in applying these or similar approaches.

KEYNOTE ADDRESS

LANDSLIDES ON STEEP FORESTED TERRAIN: THE PROBLEM AND RESOURCE MANAGEMENT IMPLICATIONS

F. Dale Robertson

INTRODUCTION

I always look forward to escaping the Washington, D.C., environment and appreciate the opportunity to return to the Pacific Northwest where the real action in forestry is.

It was a little over 10 years ago, when I was a brand new Forest Supervisor at the Siuslaw National Forest, that I first faced the challenge of trying to practice forestry on unstable terrain. I remember arriving in November 1973, and it was raining as usual. In that month we set an all-time record in Corvallis, Oregon, of 20 inches of rain. At that time, it seemed to me that the soil started to slip the moment I arrived. During that first winter we had a lot of landslides, slumps, and debris flows in the forest.

As most of you probably know, the Siuslaw National Forest is located in the Coast Range of Oregon. It has some of the most productive timber-growing land in the world, as well as some of the most productive streams for anadromous fish. Unfortunately, the Siuslaw has a lot of especially steep, unstable country, which creates the potential for a basic conflict between two very valuable and important resources--timber and fish.

By winter 1973, the controversy over timber harvesting and road building practices had built up to the point where the Oregon Wildlife Commission and the fisheries interests were no longer willing to let existing management practices continue unchallenged. In analyzing the situation, the Siuslaw National Forest staff basically agreed with many of the concerns expressed by the Oregon Wildlife Commission and decided that some change in management practices was in order. The Forest initiated an effort to bring state-of-the-art knowledge and technical expertise to bear on the Siuslaw problem. This effort also highlighted the weaknesses in the knowledge and helped focus the objectives of the newly formed Forest Service Mass Soil Movement Research Program. This was when I first met a young scientist, Doug Swanston, who came to Corvallis to help me out with my problem. It's times like this when land managers really learn to fully appreciate their colleagues in research.

Purposes of Workshop

Unlike Doug, who is still making a career out of landslides and mass soil movements, I've gone on to other things. Because of my experience at the Siuslaw, though, I've retained a high interest in slope stability; but my knowledge of the subject is really about 5 years out of date. I am looking forward to participating in this workshop, just to see how much progress has been made over the past 5-10 years.

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I think everyone has learned a lot more about slope stability since my time at the Siuslaw. Research has given us a better understanding of the mechanics of slides--of how they're triggered and how they progress. Research has also developed better assessment procedures and predictive techniques that can help to identify unstable ground and areas and situations where there is high risk of soil movement. In the next 3 days we will be talking about what is known as a result of research and identifying high-priority areas where more research is needed. Feedback is needed from the land manager on where the research program should be headed.

We have a lot more experience, too. Faced with decisions in steep, forested terrain, many land managers have taken research information and developed their own field techniques for assessing landslide hazards and risks. Look around; assembled in this room are probably more than 2,500 years of collective experience in unstable terrain--so another important purpose of this workshop is to let us share what has been learned in those years through experience and sometimes through painful trial and error.

Just to keep things in perspective, I think we should keep in mind that this problem is old and widespread. The problems of unstable terrain are not confined to the Pacific Northwest, but occur in most states and provinces,--in fact, all over the world. Last year there were mudflows in Utah that threatened Salt Lake City and other communities along the Wasatch Front. In 1981 and 1982 there were mudflows near San Francisco and at other places along the California coast. In Fairfax County, Virginia, there's a strong county ordinance controlling construction on unstable lands. One house near where I live was completely demolished when it suddenly slipped several feet downhill.

Landslides aren't new, either. In Lebanon, many centuries ago, the Phoenicians cut the cedar forests and then had to build rock-walled erosion terraces to keep the soils from slipping down the mountains.

Austria has had an active landslide control program for 100 years. There is also unstable terrain in the European Alps, in New Zealand, and in Japan. I visited Japan 3 years ago, and was shown some landslide-prone areas that reminded me of the Siuslaw country. The Japanese have put a lot of effort into building concrete structures in headwalls and other slide-prone areas to prevent landslides. This was a costly program, and the Japanese foresters weren't too sure about its effectiveness. So this is not a problem peculiar to the United States. It may seem that way at times, but colleagues around the world are also worrying about landslides.

The Nature of the Problem

Practicing forestry in steep, unstable country is one of the most challenging jobs land managers face. It is a problem that will never be completely solved, because we are up against a pretty formidable opponent--the laws of nature dealing with basic geological processes.

Those of us in Washington, D.C., sometimes get an exaggerated view of our power and influence, but we still know we can't repeal or modify the basic laws of nature--although there have been times that we have been accused of trying to do so. Rather, we have to live with the laws of nature, and strive to gain a better understanding of what is possible and how to better integrate land management actions into the the natural scheme of things. This is true whether we're dealing with logging and roadbuilding in steep and unstable country, building permanent structures in floodplains, or locating subdivisions in fuel types subject to periodic and catastrophic fires. When these sorts of things are done, eventually that 50- or 100-year flood, fire, or storm will catch up with all the past bad decisions or miscalculations.

Rising Resource Values Add to Difficulties

Making things more difficult for forest managers are the rising resource values, which make it much more costly to ignore or stay out of the higher risk areas. In the Forest Service, wise predecessors tended to bypass the tougher areas and moved on to the next ridge or drainage where it was safer to operate.

With the present restrictions on entering many of the roadless areas in the forests and having already harvested much of the timber in the more easily operated areas, we no longer have the luxury of our predecessors. We have to reconsider the "once-or-twice-passed-over" areas for development activities. Fortunately, we have more research results and better technology to deal with the problem than our predecessors ever considered possible. In many other ways, however, things aren't so easy. Public concern and pressures are greater and environmental standards and expectations are higher. The importance of water quality and anadromous fisheries are better recognized. We have to make tougher decisions about these areas of unstable terrain. Do we forego the resources within them or do we build roads, harvest the timber, use the other resources, and accept the risks?

The Manager Must Assume Some Risks

Those are basic questions and we can't just ignore them. Where the resource values warrant, we have to be cautious in taking calculated risks, yet still make judgement calls based on everything we know. And there is some probability of failure. We should understand that now and then our activities will accelerate or trigger soil movement. But how do we estimate the probability of failure? How do we measure the risks? How do we decide when to go into an area with unstable terrain, and when not to?

Let me make one thing clear before I go on: My job as keynoter is to raise questions for others to answer, not to answer them myself. And I'm thankful for that. In the past I've had to make decisions about managing unstable terrain. And my point is that when we build a road or harvest the timber in unstable areas we should know the risks we are taking in terms of both economic and environmental values.

We Must Know What We Are Doing

It all comes down to knowing what we're doing instead of guessing at it--and this is a case where research and land management must go hand-in-hand. With knowledge developed through research, managers should be able to consider development activities in higher risk areas with greater confidence. We must watch out for dangers of overconfidence, however, where our push to manage resources in unstable areas gets ahead of what we truly know about them. When that happens it's the forestry equivalent to "Russian roulette," where the only uncertainty is not whether, but when, we'll lose. In unstable areas there is no substitute for knowing what we're doing.

What we are engaged in is a perpetual duel--the efforts of human minds and human skills to contend with the basic natural processes of a continually changing earth. That means each function is important and that more is required of everyone in that flow of information, from the researcher who is studying slope stability and landslide processes, to the manager who has to decide how to manage the land and where to get the resources, and the on-the-ground, practicing technician who knows the terrain and how to apply all the knowledge. In reality, we're no stronger than our weakest link.

Challenge to Research

Research has made great strides in recent years, but for all we've learned in the past we need to learn still more. Most specifically, we need more engineering research, better designs for forest roads and other structures in critical unstable areas. We also need to improve our techniques of risk assessment and we need better quantification of downslope damage when the slope fails.

Research has done a lot to help us evaluate risks and to capably take on reasonable risks that were foolish to assume a decade ago; but we need to continually shove back those limits, with research showing us the way. Part of the purpose of this workshop is to assess where we are and to identify our highest priority research needs.

Challenge to Land Managers

In the final analysis, though, it comes down to the land managers who have to make the judgement calls about what will be done. All of the research knowledge in the world is useless at that point unless the managers know how to use it and know the terrain they are working with.

Managers have to know how to use the information that research produces. One reason why we are having this workshop is because of the inadequate extension job--the insufficient transfer of knowledge--in slope stability work. There's been a good flow of slope stability information coming out of research--and the inter-Station slope stability research program has been especially productive--but research results need to be translated into practical guidelines for land managers.

That said, let me set out a few points about what I think land managers need to do in managing unstable country. First--as they say in one advertisement I've seen--we have to recognize that "there are no easy answers, only intelligent choices" in working with unstable terrain. We need to make intelligent choices and ask for help by reaching out for the best experience and expertise available. At the Siuslaw we faced very difficult decisions concerning high timber values and the immensely important anadromous fisheries resource. And so we called in some of the best experts we could find. Doug Swanston came in to help. We brought in experts from the regional office, a biologist from the wildlife commission, and a hydrologist, a soil scientist, and engineers from the Siuslaw National Forest staff. They spent 6 months working with us on our slope stability problems, and several of these people are here today. We made some informed, intelligent choices about what we do, and we reduced the potential for future problems.

My second point about the challenge to land managers is that there is no substitute for knowing the ground. The people on the ground are the first line of prevention if they know what areas are risky and under what circumstances--and after they've been through slumps and slides and creeps and flows, they can tell you a lot about how to avert them.

In meetings like this we sometimes tend to overlook the importance of the on-the-ground practicing technician--the people who actually locate and design the roads and timber sales. There is just no substitute for people who have the experience that comes from living with the problem for 5 years or more and who have developed a special sense or "feel" for the land and what you can or cannot do with it--though they still have to supplement that knowledge with the latest scientific techniques.

Much of what I've said here may remind you of that recruiting ad for the Army. The problems of unstable terrain require that everyone involved "be all that they can be." They require that researchers be productive and working on the highest priority problems; that land managers be wise and sensitive to both economic and environmental values and that the on-the-ground practicing technicians know the land and apply all there is to know from research and from experience. We have to be willing to take reasonable, calculated risks while doing our best to mitigate any resulting damage.

My final point, though, is that sometimes our best won't be quite good enough; and in those instances we have to be willing to admit it. It's sometimes tough to do that--to admit that despite everything we know or could economically do to mitigate the risks, we still couldn't build a road or develop the resources in an area without the soil slumping or land sliding. But when that's the case we need to back away. We need to remember that the soil is our most fundamental resource. It may have taken many thousands of years to put a foot of soil on a forested slope and it is unwise to lose it in a year.

SUMMARY

Let me close by summarizing some of my conclusions, based on my experience in trying to practice forestry in steep, unstable country:

1. In spite of our cadre of very competent, hard-working scientists, there is no "miracle" out there waiting to be discovered that will solve the problem. Likewise, there is no "magic" or "heroic action" out there just waiting for a brave, courageous land manager to come along to take bold action.

2. I don't think it's realistic to accept the view expressed by some people that we should be overly cautious and back away or delay management activities on millions of acres of forest land until research provides the basis for risk-free decisions. That is not realistic and will never happen.

3. I do accept the view that progress comes slowly and, I hope, cumulatively over time based on hard work, good judgement, and experience by everyone involved--researchers, land managers, technical specialists, and on-the-ground practicing technicians.

I think we're at a point where pooling our knowledge and experience has the biggest payoff of anything we could do--and that is the primary purpose of this workshop. It must not stop here this week, however. The acceleration of technology tranfer over the next few years probably will have the largest payoff in terms of results on the ground.

I know you're going to have a successful workshop, but this workshop should be viewed only as a beginning.

SURVEY OF SLOPE STABILITY PROBLEMS ON FOREST LANDS IN THE WEST

Edward R. Burroughs, Jr.

ABSTRACT: Within the region west of central Montana and north of San Francisco, the intersection of areas with high hazard levels for natural landslides, important fishery-water resources and major levels of management activity represent areas with a large potential for environmental damage as a result of timber harvest. The magnitude and frequency of slope stability problems increases from east to west and from south to north. The percentage of land in the Northern, Intermountain, Pacific Northwest and Pacific Southwest Regions with a high potential for mass failures ranges from 10 to 12 percent. This percentage at the forest level ranges from 0 to 45 percent. Road construction costs per mile increase by a factor of about 4 from south Idaho to Washington and Oregon. Annual road maintenance costs can increase by a factor of 13 in areas with a high potential for road cut failures. Intensive slope stability surveys can be used to identify timber harvest sites within a larger area generally classified as unstable.

INTRODUCTION

The Pacific Northwest States are blessed with climate and soils that produce abundant forests, clear streams, and important habitat for anadromous and resident fishes. Unfortunately, the climate, geology,and topography frequently produce sites with a high potential for landslides. The risk of damage to fisheries and water quality by landslides caused by timber harvesting and road construction is one of the most serious problems facing land managers in the Pacific Northwest.

The quality of fisheries and water is a very sensitive issue in the northwestern United States, and the public frequently questions the impact of Federal timber sales. Many management decisions regarding road location and design and timber sale layout hinge directly on the potential effect on the fishery-water resource. This paper will describe the magnitude, intensity, and distribution of slope stability problems within the northwestern United States. The impact of slope instability on road construction and road maintenance costs will also be discussed. The area of consideration is western Montana and northern Idaho (USDA Forest Service, Northern Region); western Wyoming, southern Idaho, Utah, and Nevada (Intermountain Region); northern California (northern part of the Pacific Southwest Region); and Oregon and Washington (Pacific Northwest Region).

LOCATION OF SLOPE STABILITY PROBLEMS IN THE WEST

Areas with a high potential for mass failure are the result of interactions between parent

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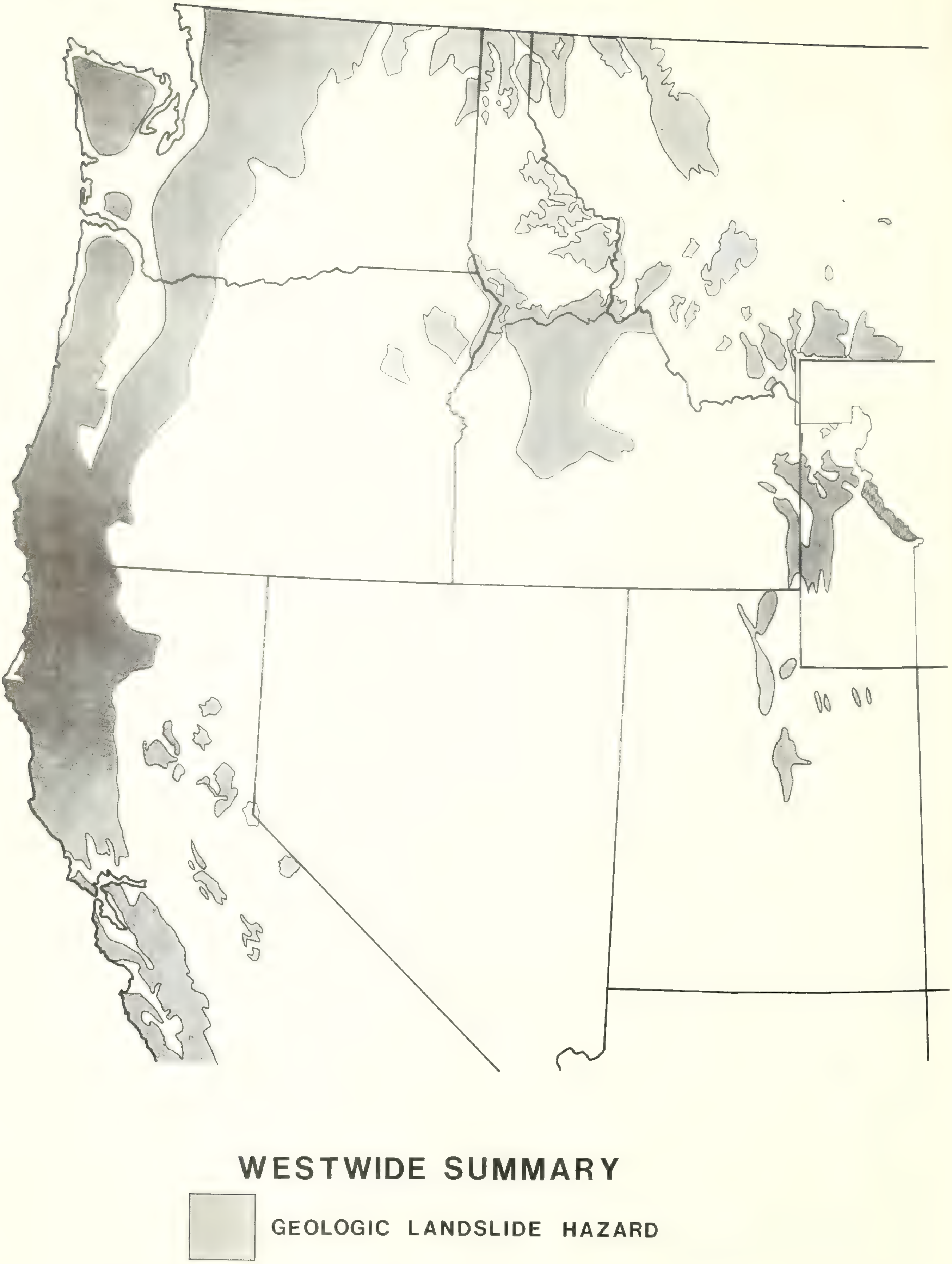

Figure 1.--Geologic landslide hazards west-wide.

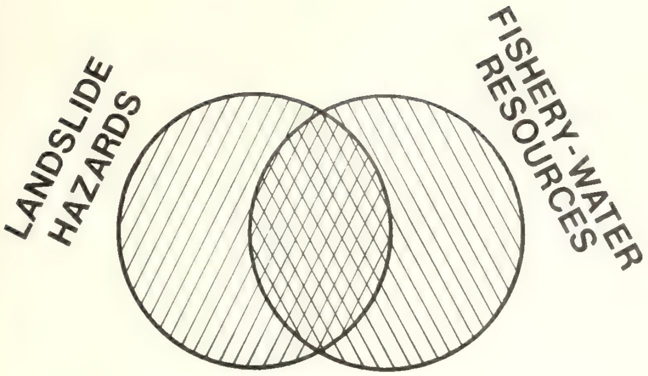

Figure 2a.—Intersection of natural landslide hazard areas and fishery-water resources.

material, topography, and climate. The methodology used to describe stability problems was to consult geologic reports and maps on a West-wide, Regional, Forest, and in some cases, District and project scale to determine the location of intrinsically unstable parent materials. These included deeply weathered sedimentary formations, granitic batholiths, weathered metamorphics, and weathered intrusive and extrusive volcanic materials. Extensive areas of particularly steep topography, regardless of parent material, were also identified as having a high potential for mass failure.

The effect of climate was introduced by mapping the distribution of annual precipitation 20 inches or greater. I assumed that at least this amount would be required to generate enough subsurface water to create instability by increasing pore water pressure. Although 20 inches annual precipitation is quite low for the West Coast, the 20-inch limit is necessary on a West-wide basis to include areas in Idaho and Utah that are known to be unstable. The intersection of significant annual precipitation, unstable geologic materials, and steep topography locates areas with a natural, or geologic landslide hazard. Figure 1 shows these areas on a West-wide basis.

The fishery resource provides a good indicator of the risk of environmental damage from landslides, not only because of the fishery value, but because this resource is intimately involved with water quality. The location of significant fishery habitat is used throughout this report as an indicator of fishery-water resources at risk from mass failures.

Figure 2a illustrates the intersection of natural landslide hazard areas and areas with significant fishery-water resources. The area within the intersection represents the potential for damage to this resource from naturally occurring landslides. Land management activities, principally road construction, oil and gas exploration, and timber harvest, can increase the frequency of landslide occurrence far above the natural, or geologic rate. Figure 2b shows the intersection of areas with a natural landslide hazard, areas with a significant fishery-water resource, and areas with land management activities. The central portion represents areas with the potential for damage to the fishery-water resource as a result of land management-induced landslides.

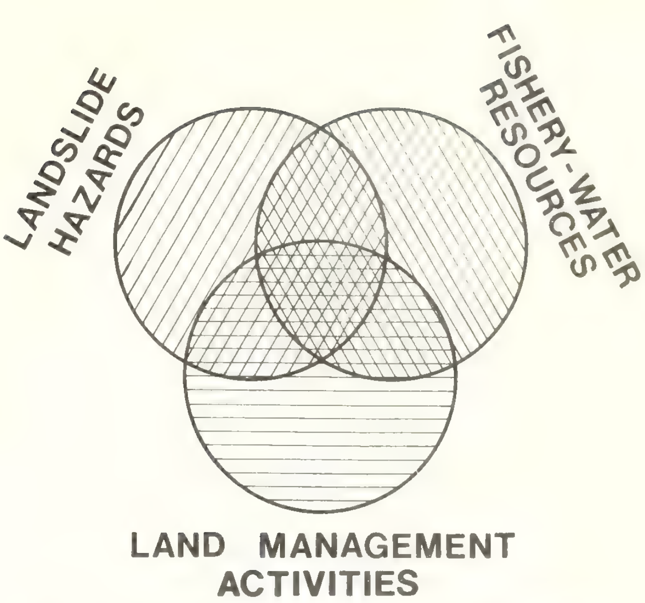

Figure 2b.—Intersection of natural landslide hazard areas, fishery-water resources, and land management activities.

The intensity of land management activity on western forest lands is indicated by the annual timber harvest volume in millions of board feet (MMBF). Timber harvest incorporates both the harvest activity and timber access, usually road construction. Data on timber harvest volume, miles of road construction, and road costs for 1979 were collected from National Forests in the various Regions. The year 1979 was selected because thereafter a recession reduced timber harvesting activity.

National Forest timber harvest volume for each Region was divided into three classes, high, medium, and low, to indicate three levels of activity. Intersections of natural landslide hazard, significant fishery-water resources, and National Forests in the three timber harvest volume classes are shown for the Regions.

NORTHERN REGION (REGION 1)

Total areas with stability problems within each Region cannot be determined accurately from Regional data because each National Forest has its own criteria for defining, inventorying, and reporting lands in this category. Also, many Forest plans are not yet complete, and the completed plans will include more accurate data than is now available. The most common denominator for comparing stability problems among Regions is to total all lands in each Region classified as either "Marginal,"

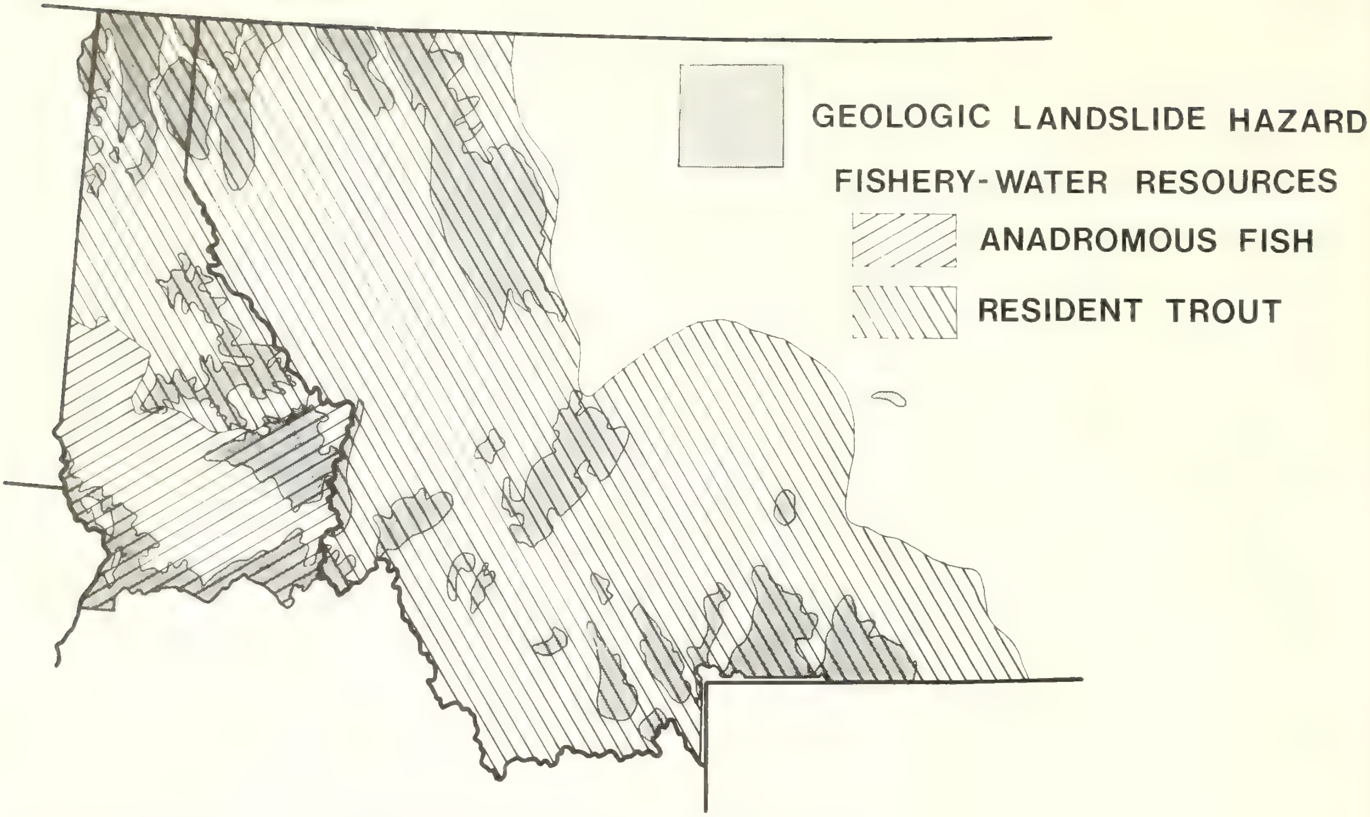

Figure 3a.--Region 1. Landslide hazards and fishery-water resources.

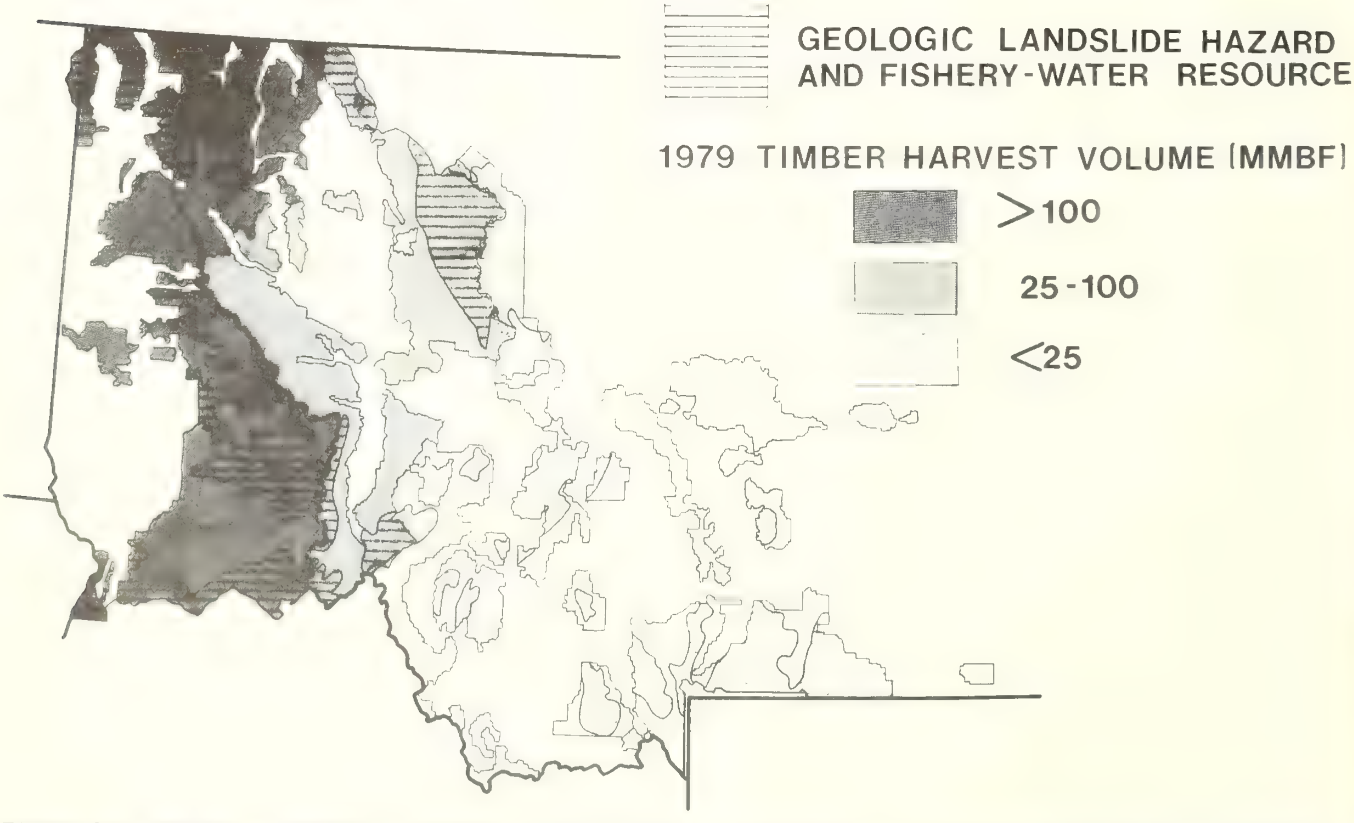
GEOLOGIC LANDSLIDE HAZARD AND FISHERY-WATER RESOURCE
1979 TIMBER HARVEST VOLUME (MMBF)
>100
25-100
<25

Figure 3b.--Region 1. Natural landslide hazard areas, fishery-water resources, and National Forest lands by timber harvest classes.

"Marginal-Unstable," "Unaccessible," "Inoperable," or "Steep Slope Lands." This total for each Region will be designated as the "High Potential" in this report. Region 1 has 10.3 percent of its lands in the "High Potential" category.

Figure 3a shows the habitat for anadromous and resident trout plus the landslide hazard areas for Region 1. The intersection of these areas represents the potential for damage to fishery-water resources from natural landslides. This intersection is overlaid in figure 3b with the timber harvest volumes of National Forest lands. Timber harvest volumes are divided into three activity classes to show how much of each Forest has a significant landslide hazard. This figure also shows those areas with a potential for management-induced landslide damage to fishery-water resources.

INTERMOUNTAIN REGION (REGION 4)

High-potential lands in Region 4 occupy 17.7 percent of the total forest lands. This estimate may be high because the Region's definition of marginal lands includes some "steep lands" and lands with unmarketable species and other economic problems. A more reasonable, though strictly subjective, estimate would be that 12 percent of the Region's lands have a significant potential for mass failure. Figure 4a shows that many of the geologic hazards and habitat for anadromous fish and most resident trout are concentrated in southern Idaho in six National Forests: the Boise, Challis, Payette, Salmon, Sawtooth, and Targhee. High potential lands for these Forests are 56.5 percent of the total high-potential lands in Region 4. Figure 4b shows those Forests with significant slope stability problems.

PACIFIC SOUTHWEST REGION (REGION 5)

Figure 5a shows fish habitat and natural geologic hazard areas for the northern part of Region 5. The Region provided information on four National Forests in northern California: the Klamath, Six Rivers, Shasta-Trinity, and Mendocino. Areas classified as "Marginal-Unstable" for these four Forests totaled 1.2 percent of National Forest lands. These data were taken from current, approved timber management plans developed in 1971-74 (exception is data from 1983 Mendocino plan), and do not include unaccessible or inoperable lands that may also have a high potental for mass failure. According to the Region, "the areas of forest land classified as unaccessible, inoperable, or marginal-unstable are being determined in conjunction with the current land management planning efforts by the Forests... The marginal acres from these Timber Mangement Plans will probably greatly increase when the new Land Management Plans are completed... In general, lands falling under these three Classifications [unaccessible, inoperable, marginal-unstable] will vary between 8 to 20 percent of the total acres on any particular forest." If it is assumed that these three classifications represent high-potential areas, then 8 to 20 percent for any of these four Forests is reasonable. Figure 5b shows slope stability problems on Forest lands in northern California.

PACIFIC NORTHWEST REGION (REGION 6)

The best general description of the situation in Region 6 is contained in a 1979 document prepared for the Regional Forester by Robert Meurisse, regional soils scientist. "Unstable soils are common in Region 6. About 11 percent (2,712,000 acres) of the Region has soils that are moderately unstable or unstable.[1] They have important implications for the development of forest resources. Some of the most unstable areas are presently being developed or will be within the next 10 years. Unstable soils are among the most productive in the Region... Some have as high as 100 MBF/acre. These soils are widely distributed throughout the Region, but are dominantly on the Western Cascades and Coast Range. Some of the most extensive acreages are in watersheds with high value anadromous fisheries, in municipal supply watersheds, upstream from reservoirs, and in areas of high visual resource quality." Figure 6a shows the location of geologic hazard areas and important fish habitat in the Region, and figure 6b shows those Forests with slope stability problems.

GENERAL REGIONAL SUMMARY

West-wide data indicate that the magnitude and intensity of slope stability problems increases from east to west and from south to north. The total percentage of land in each of the Regions with a high potential for slope stability problems ranges from about 10 to 12 percent. This percentage at the Forest level ranges from 6 to over 45 percent, depending upon whether the Forest is at the drier (eastern or southern) or wetter (western or northern) side of the region.

Figure 7 shows the location of National Forest lands with a potential for damage to fishery-water resources as a result of management-induced landslides. The darkest tones in the figure represent the greatest potential for damage within each Region based on timber harvest classes. Figure 7 is a summary of figures 3b, 4b, 5b, and 6b, and represents the situation on National Forest lands within each Region. Because of the increased intensity and severity of stability problems from east to west, areas with high potential for damage in Regions 1 and 4 are probably equivalent to a moderate potential in Regions 5 and 6. On the basis of my

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[1] Only tracts of 5,000 acres, or larger, have been considered. Additional acreage is found in smaller, isolated tracts.

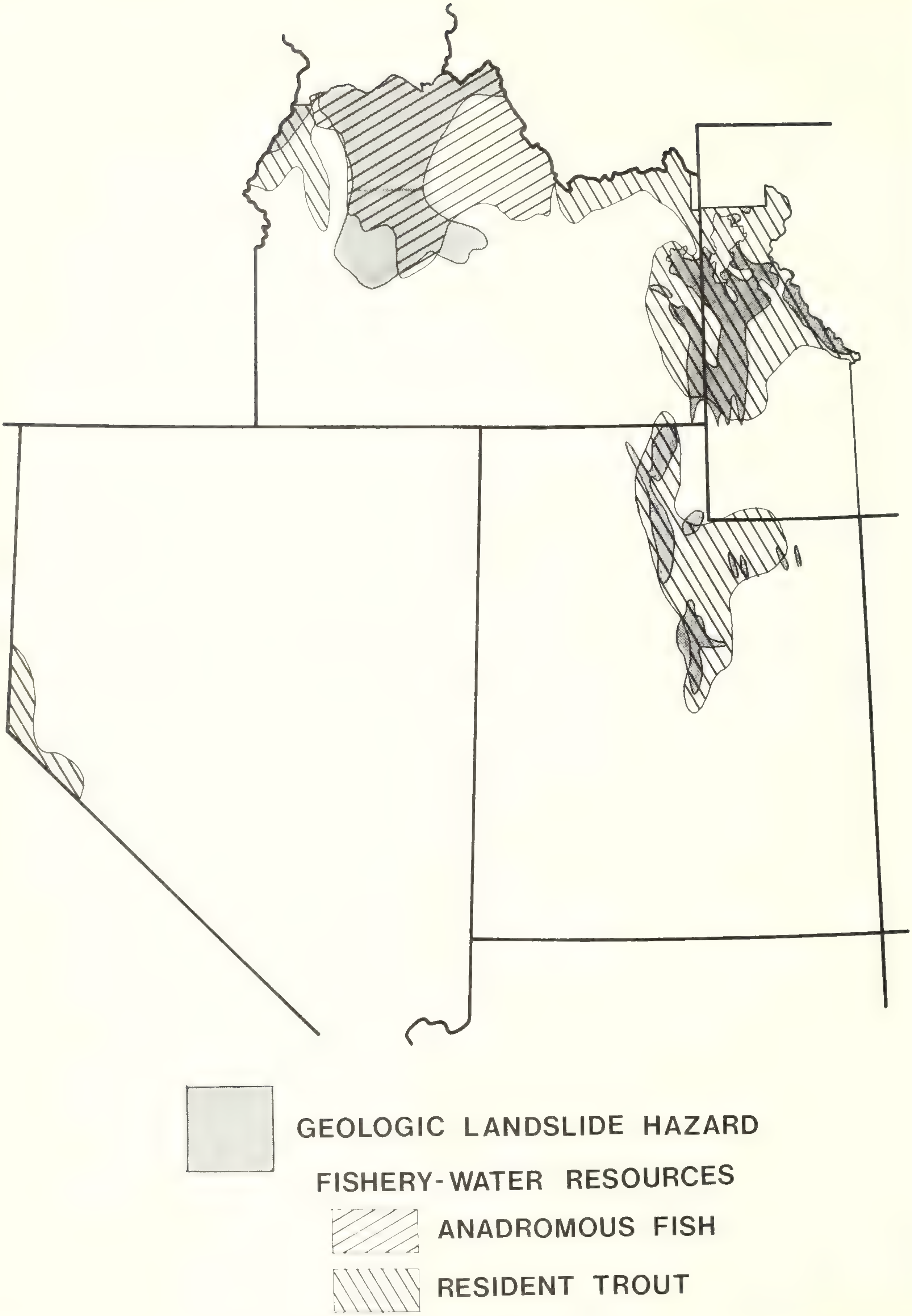

Figure 4a.--Region 4. Landslide hazards and fishery-water resources.

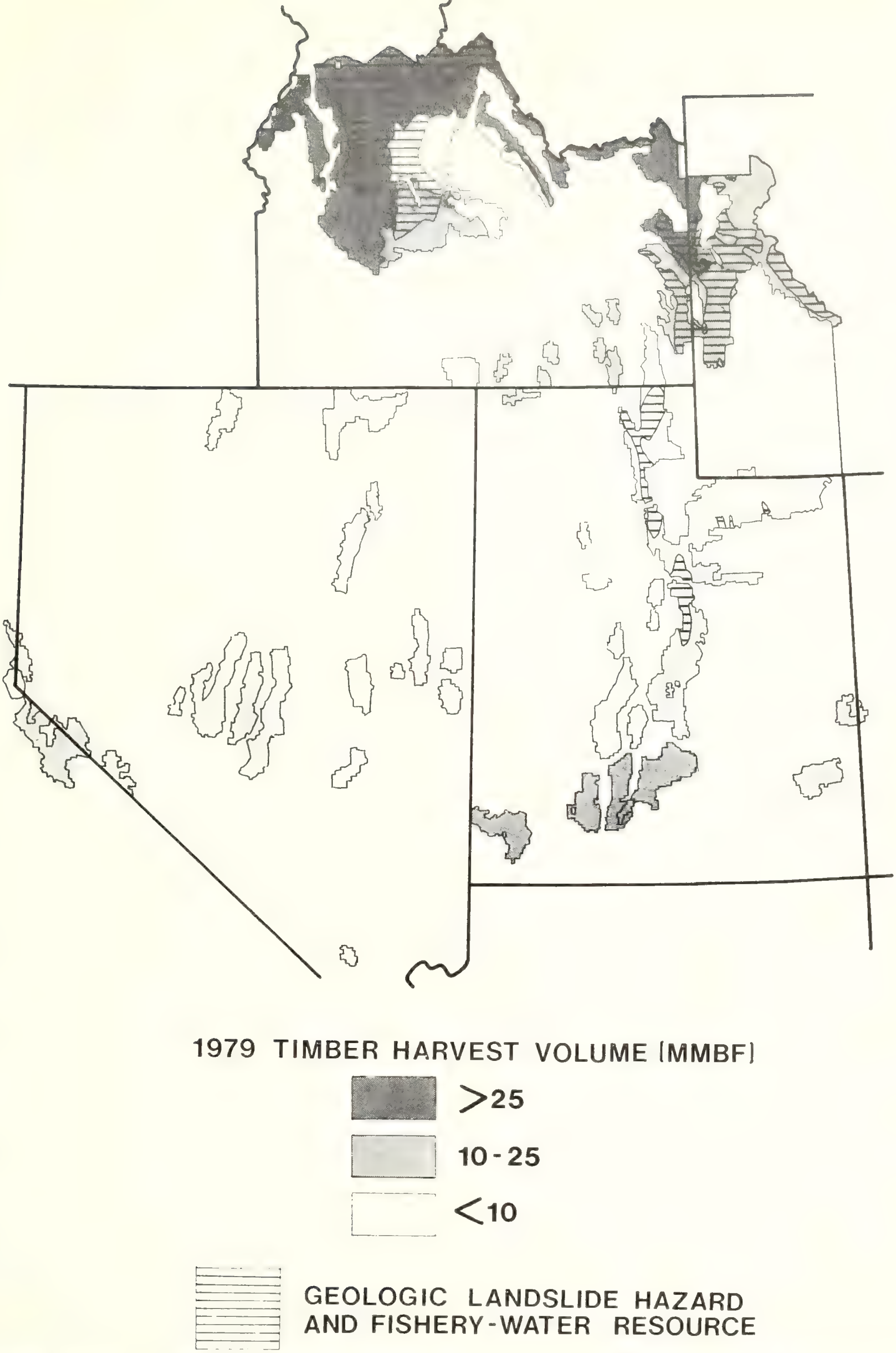
1979 TIMBER HARVEST VOLUME (MMBF)
>25
10-25
<10
GEOLOGIC LANDSLIDE HAZARD AND FISHERY-WATER RESOURCE

Figure 4b.--Region 4. Natural landslide hazard areas, fishery-water resources, and National Forest lands by timber harvest classes.

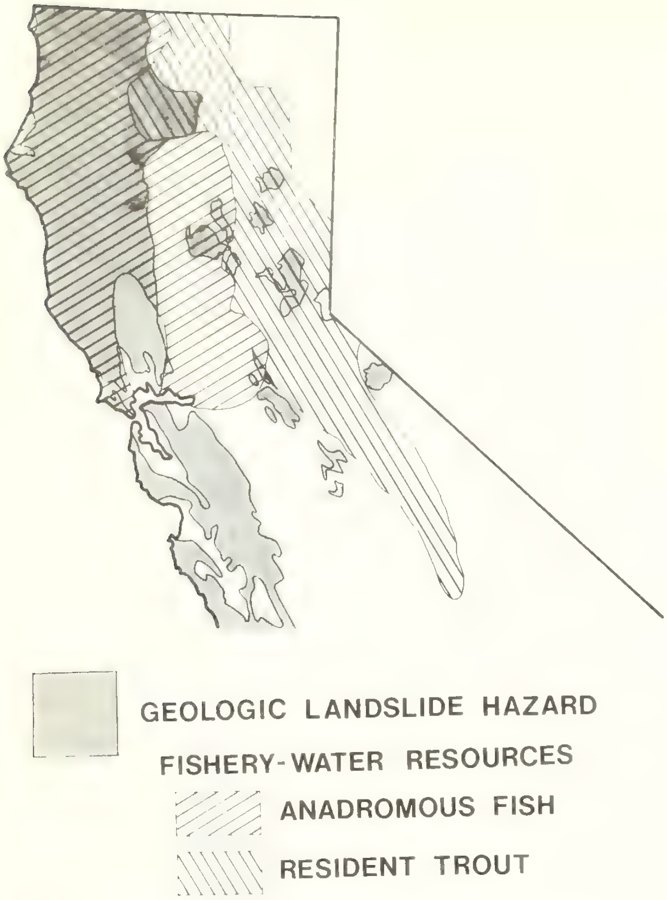

Figure 5a.--Region 5. Landslide hazards and fishery-water resources.

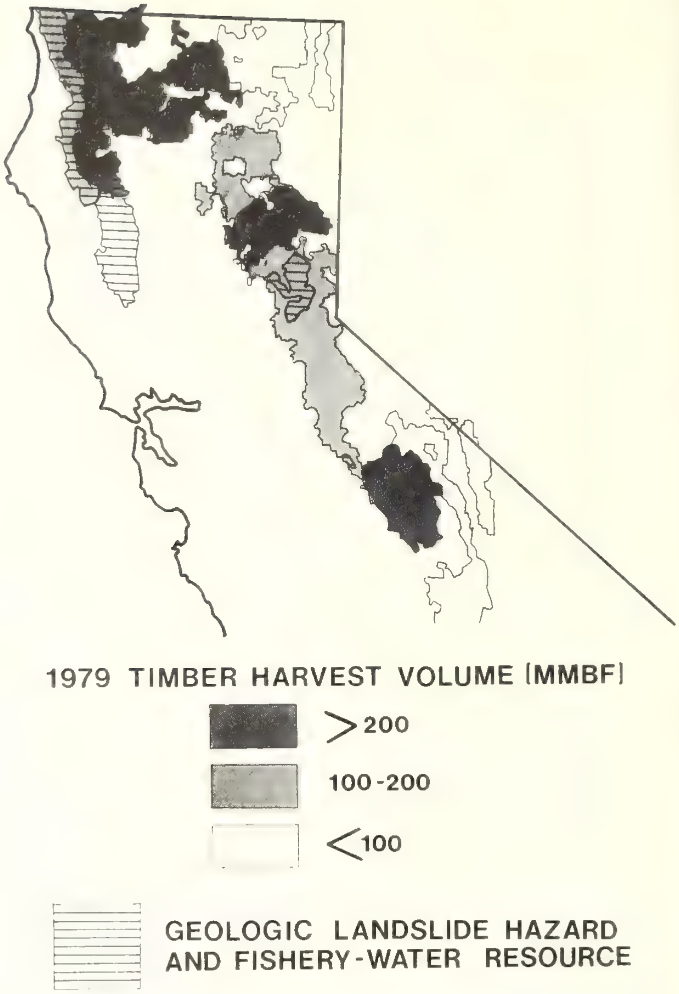
1979 TIMBER HARVEST VOLUME (MMBF)
>200
100-200
<100
GEOLOGIC LANDSLIDE HAZARD AND FISHERY-WATER RESOURCE

Figure 5b.--Region 5. Natural landslide hazard areas, fishery-water resources, and National Forest lands by timber harvest classes.

own West-wide observations, I have ranked the relative stability on National Forest lands across the four Regions with a four-level rating system as shown in figure 8.

ROAD CONSTRUCTION RELATED TO SLOPE STABILITY

As the stability problems become more extensive and more severe from south to north and from east to west, road construction costs increase accordingly. These increased costs are in response to the need to maintain the annual cut and provide environmental protection under increasingly difficult conditions.

Road construction costs in two National Forests illustrate the differences between the east and west sides of Region 1. The Gallatin National Forest, east of the Continental Divide, built 7.6 miles at $39,921 per mile in 1979. The Clearwater National Forest, on the west side, built 43.3 miles per year in 1979-80 at an average cost of $61,690 per mile. Using these figures, the miles of construction increased by a factor of 6 and the cost per mile increased by a factor of 1.6 from east to west. Region 4 road costs for southern Idaho in 1979 ranged from about $22,000 per mile for the Targhee National Forest to about $50,000 for the Boise and Payette. Average new road construction in the Klamath, Six Rivers, Shasta-Trinity, and Mendocino Forests in Region 5 in 1979 was 46.3 miles per Forest at a cost of $44,487 per mile. Road construction in 1979 in Region 6, west of the Cascades, averaged $124,000 per mile. Costs were about $41,000 in the Umpqua National Forest, $92,000 in the Siuslaw, $150,000 in the Willamette, $160,000 in the Mt. Hood, $123,000 in the Gifford Pinchot, and $177,800 in the Olympic.

An engineer from Region 6 explained that the easily accessible terrain has been developed. The remaining undeveloped country has much steeper slopes (100-percent slopes are not uncommon) and requires more blasting, and 5- to 6-foot stumps increase clearing costs. Endhaul of excavated material is very expensive but is required on steep slopes to avoid sidecast. More endhaul, steeper slopes, and more blasting were also cited as reasons for increased road costs from east to west in Region 1.

Within most Forests, the engineers, planners, and resource specialists usually act as a team to examine alternate routes for road locations to

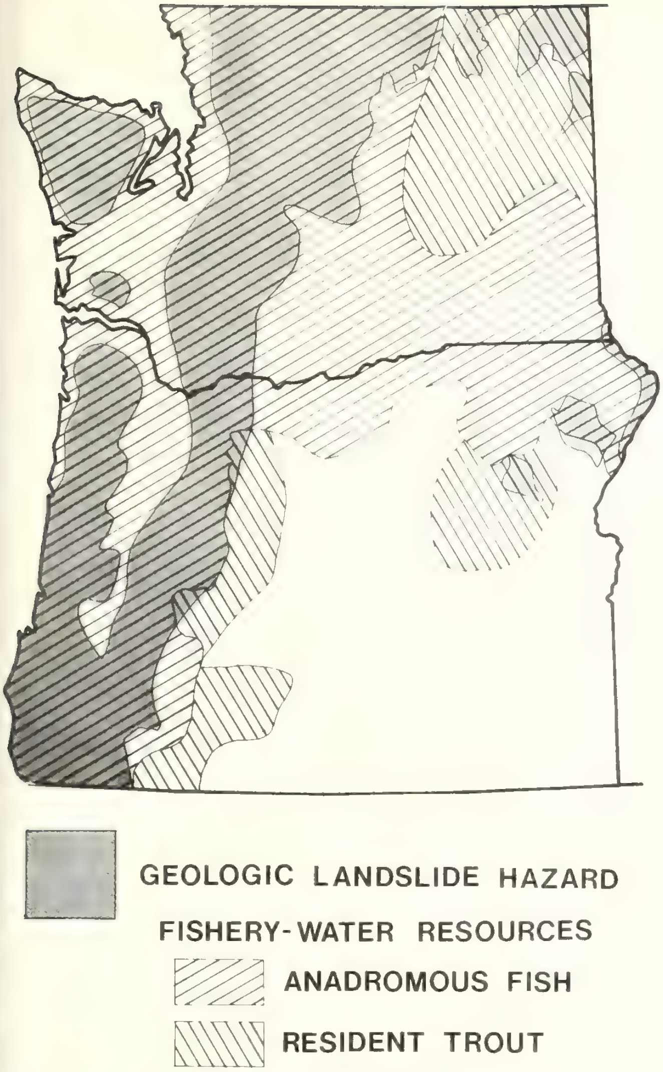

Figure 6a.—Region 6. Landslide hazards and fishery-water resources.

determine which will provide the most environmental protection for the least cost. A numerical example of the evaluation of alternate road locations was provided by Edward Butler (engineer) and Dale Wilson (soil scientist) of the Clearwater National Forest, Region 1. This Forest uses a computer program to determine road costs as a function of road specifications, topography, and distance through land type units. Each land type is characterized as to sideslope, degree of dissection, percent rippable rock, soil depth, mass failure costs, and slope stabilization class (for protection against surface erosion). Cost estimates are developed using these characteristics as variables, except for the cost of mass failures, in which case a cost per mile is estimated. The mass failure cost reflects techniques that must be used to prevent mass failures. Road cost per mile for each land type is the sum of the costs for each characteristic. Road costs per mile can increase by a factor of about 3, depending upon characteristics of the land type involved and the mass failure hazard.

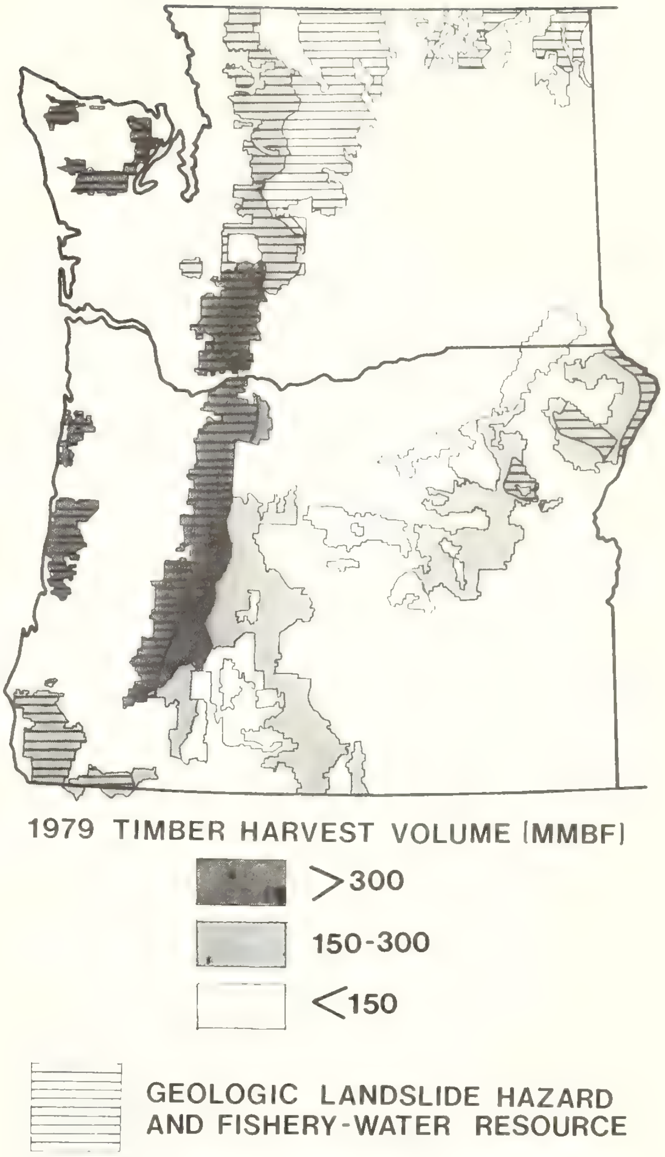
1979 TIMBER HARVEST VOLUME (MMBF)
>300
150-300
<150
GEOLOGIC LANDSLIDE HAZARD AND FISHERY-WATER RESOURCE

Figure 6b.—Region 6. Natural landslide hazard areas, fishery-water resources, and National Forest lands by timber harvest classes.

ROAD MAINTENANCE COSTS RELATED TO SLOPE STABILITY

Little information is available on increased road maintenance costs attributable to slope stability problems because of a lack of reporting procedures within and among Regions. Available data provides some insight into this subject. Robert Meurisse, Region 6 soils scientist, estimates that road maintenance costs increase 50 to 100 percent in areas with stability problems. The most detailed information was provided by Larry Rich, Region 6 Engineering, on volumes of slide material removed from roads after the winter of 1981-82. The average slide volume removed from each of six westside forests was 26,385 yd^3. If we assign a unit cost of $4.50 per yard, the average removal cost per westside Forest was $118,730. For three Forests east of the Cascades, the comparable average volumes and costs are 1,961 yd^3 and $8,825. These figures

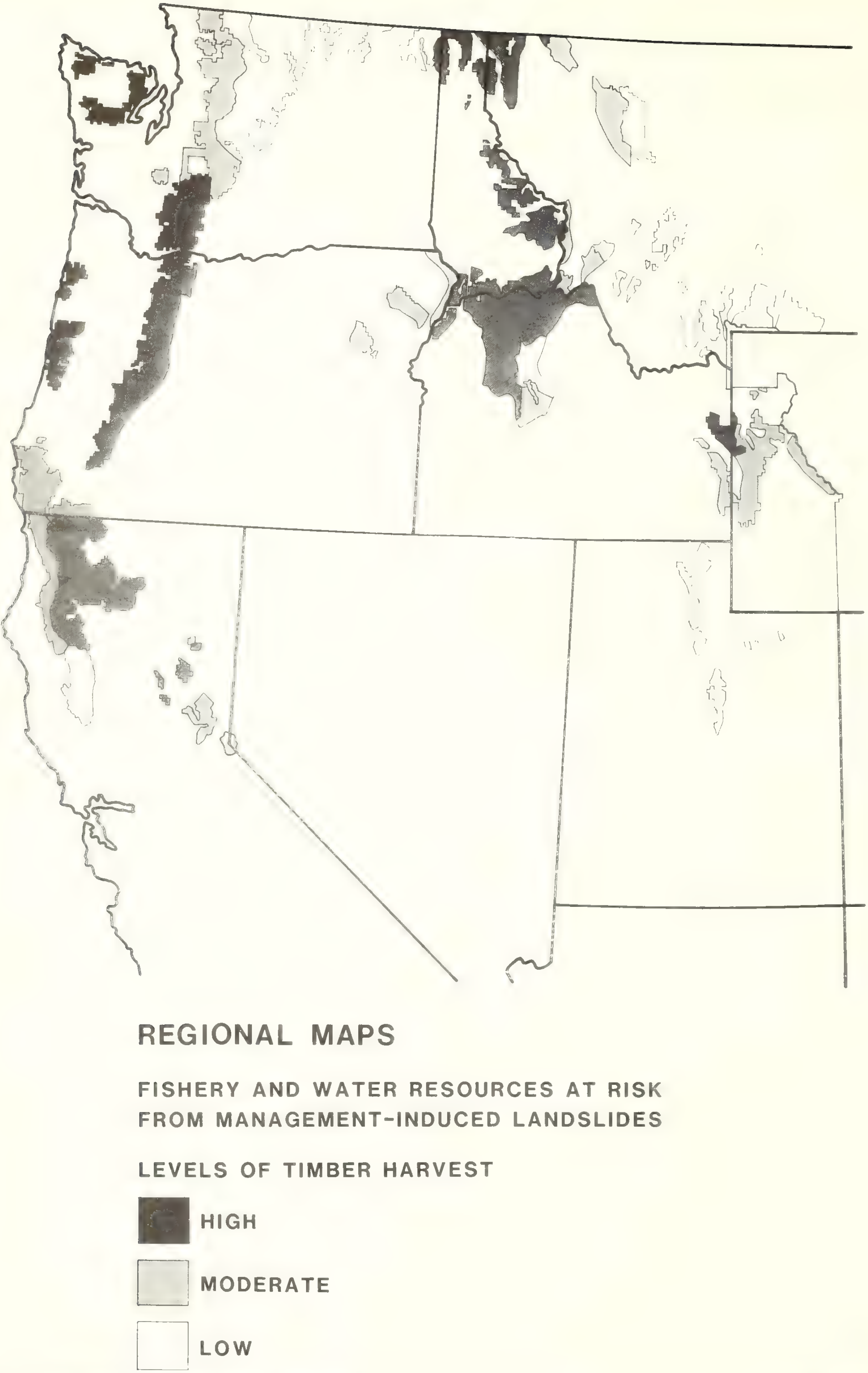
REGIONAL MAPS
FISHERY AND WATER RESOURCES AT RISK FROM MANAGEMENT-INDUCED LANDSLIDES
LEVELS OF TIMBER HARVEST
■ HIGH
▨ MODERATE
☐ LOW

Figure 7.--Regional distribution of National Forest lands with potential for landslide damage to fishery-water resources as a result of timber harvest activity.

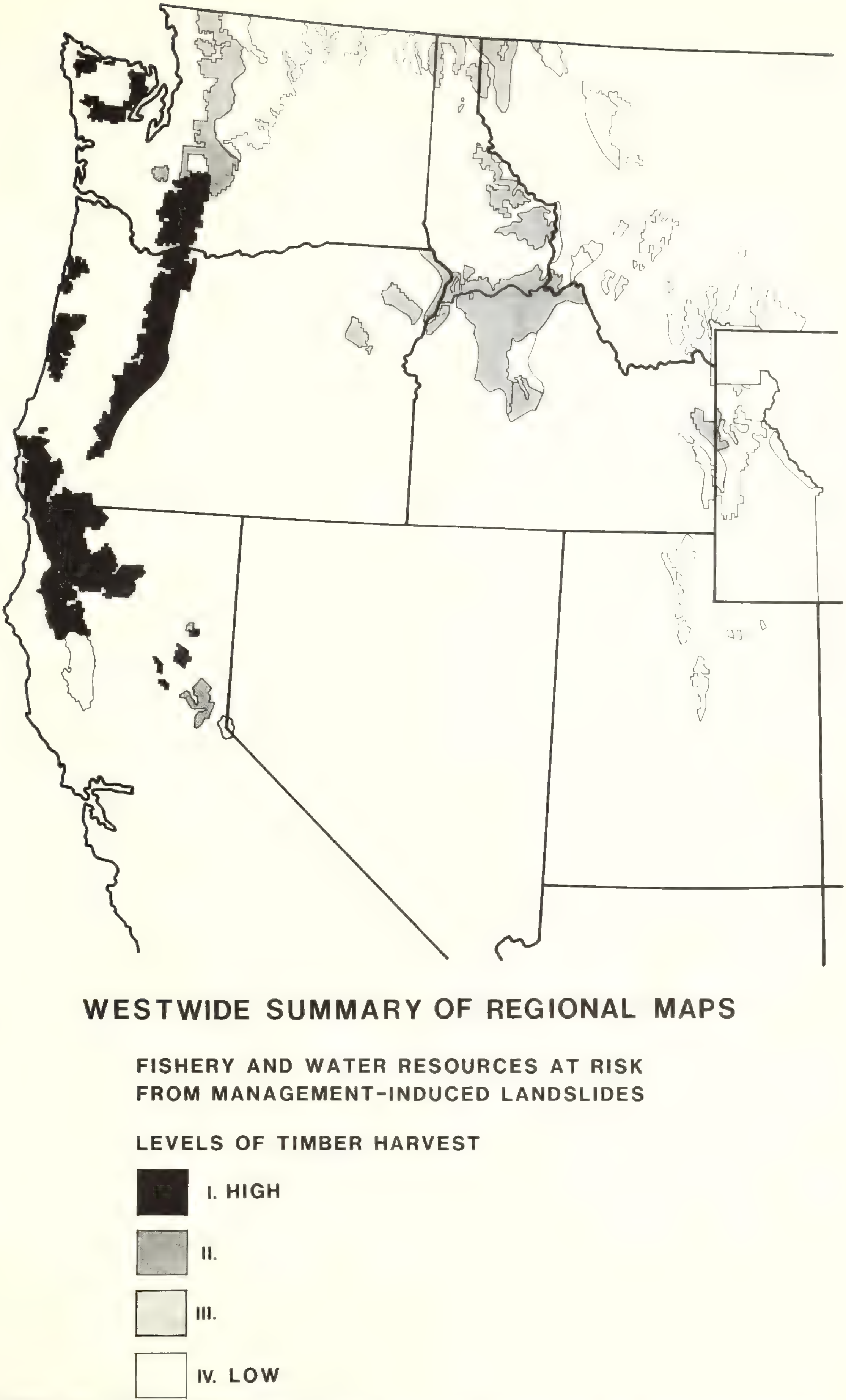
WESTWIDE SUMMARY OF REGIONAL MAPS
FISHERY AND WATER RESOURCES AT RISK FROM MANAGEMENT-INDUCED LANDSLIDES
LEVELS OF TIMBER HARVEST
I. HIGH
II.
III.
IV. LOW

Figure 8.--West-wide summary of National Forest lands with a potential for landslide damage to fishery-water resources as a result of timber harvest activity.

refer to cut slope failures that deposit material on the road surface. Slide removal costs for slide-prone westside Forests are about 13 times that for the more stable eastside Forests.

The Eugene District of the Bureau of Land Management, U.S. Department of the Interior, in western Oregon faces increased road maintenance costs caused by cutslope failures. The average volume removed annually from 1979-82 was 42,419 yds over 600 miles of road. About 13 percent of this volume was mass failure of the road cut slope (14,140 yd^3), while the remainder was minor "sluff" or dry ravel. About 20 percent of the mass failure volume (2,828 yd^3) reaches a culvert and was deposited in a stream.[2] If we assign $4.50 per yd^3 for slide removal, then the 80 percent of the material remaining on the road costs the Eugene District $50,904 per year to remove.

Landslides, particularly those that involve the fill slope and the road surface, are difficult and expensive to repair and stabilize. Repair of fill failures is often hasty and accomplished by dumping loose material into the gap to bring the road back to grade--this may be repeated several times a year. Landslides may require engineered structures or augered-in perforated pipe to provide support and reduce pore water pressures to prevent repeated failure. Meurisse reports the average cost of stabilizing three slides in the Siskiyou National Forest was $100,000. Average annual repair costs for landslide damage in the Clearwater (1974-76) was $55,800, and landslide stabilization costs for 1974 were $1,100,000.

One of the best, although expensive, methods to prevent fill failures on existing roads is to remove sidecast material that shows signs of instability. The Siuslaw National Forest began a "Sidecast Pullback" program in 1974 to correct problems caused by mass failures in "uncompacted fill deposited on an unprepared side slope." The problem was compounded by the decay of roots that anchored stumps to the slope when these stumps were covered by fill. "With time, organic material decayed, fills settled, and slides were generated by the hydraulic and gravitational forces acting on the unstable material. Debris torrents of several hundred cubic yards are sometimes triggered by the failure of a small amount of unstable sidecast material." Since 1974, about 45,000 yd^3 of sidecast have been removed from 120 high-priority sites at a cost of $94,000.[3] In 1980, the program was evaluated and the management team decided to continue this work. The magnitude of the unstable sidecast problem is indicated by their estimate that 250,000 yd^3 could be removed in the Siuslaw at a cost of over $1,000,000.

SLOPE STABILITY LIMITATIONS ON DEVELOPMENT

A distinction must be noted between areas classified as having: (a) high potential for mass failure; and (b) areas actually withdrawn from the timber base because of stability-related problems. In the first category, some lands may be routinely developed, using intensive investigations and precautions for environmental protection. Other areas in this category may be deferred for later development in the hope that improved technology may reduce the risk of environmental damage. There is some concern that development on deferred areas may be hindered by development on areas with fewer problems.

Areas actually withdrawn from the timber base are the "hard core" areas wherein no improvement in technology is likely to add to the timber base. Improved methods for identifying and evaluating slope instability may increase the amount of lands classified as unsuited for timber production. But more importantly, such advances in knowledge will provide the technical basis for sound, defensible management on lands with a high potential for mass failures. Improved road construction technology, including better stabilization techniques, will undoubtedly reduce the risk of environmental damage when development does proceed in unstable areas.

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[2] Personal communication with James McLaughlin, soils scientist, Eugene District.

[3] Siuslaw National Forest Staff Report on file at Siuslaw National Forest Supervisor's Office, Corvallis, Oregon 97330.

FACTORS INFLUENCING THE STABILITY OF SLOPES

R. C. Sidle

ABSTRACT: Important geologic factors and soil properties influencing the stability of slopes include strength and structure of rock material, bedding sequences, slope gradient, landform shape, soil depth, soil strength, and clay mineralogy. Shallow, rapid failures, such as debris avalanches, are often initiated by extensive pore water pressure buildup within the soil mantle resulting from high-intensity or long-duration storms. Acceleration or initiation of deep-seated, soil mass movements (for example earthflows) may result from a gradual accumulation of seasonal rainfall. Rate of water movement into and through unstable landforms is critical in determining groundwater conditions and can be greatly influenced by the extent and continuity of soil macropores. The influence of plant rooting strength on slope stability is most apparent where extensive clearcutting or vegetation conversion has occurred. Other land management practices, such as road building and residential development, may cause mass failures by overloading or undercutting unstable slopes and by concentrating surface and subsurface water.

INTRODUCTION

Natural factors influencing the stability of forested hillslopes can be catagorized into five process-related areas: (1) geologic/geomorphic factors, (2) soil properties, (3) hydrologic factors, (4) vegetative factors, and (5) seismicity. The importance of most of these factors can be modified by forest management activities; however, the scope of this paper will deal more directly with specific natural factors and processes involved in landslide initiation. It is essential that land managers understand the basic processes controlling slope stability before site-specific prediction, avoidance, and ameliorative measures are applied.

GEOLOGIC/GEOMORPHIC FACTORS

Influence of Rock Composition and Structure

Geologic factors predisposing certain terrain to soil mass movement include weak or soft rock composition, undesirable structure, and unfavorable bedding sequences. Throughout North America there are numerous examples of particular types of soil mass movement characteristically associated with certain rock or weathered regolith material. These include large earthflows associated with the Franciscan sedimentary assemblage of northern California; volcaniclastic rocks of the western side of the Cascade Range and the Columbia River Gorge; rotational failures associated with weathered shales and siltstones of north-central Texas and the northern Oregon coast, and debris avalanches associated with competent sandstone and compact glacial till in the mountains of coastal Oregon and Alaska, respectively.

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Weak rock types reflect the extent of weathering as well as the relative strength of the geologic material. In high rainfall areas, sedimentary and volcaniclastic rocks may weather into deep, clay-rich soils that are susceptible to deep-seated soil creep and earthflows. Such soil mass movements are typical on slopes of the northern California Coast Range and the western side of the Cascade Range. Kelsey (1978) estimates that approximately 10 percent of the Franciscan melange in the northern California Coast Range is comprised of active earthflow terrain. Along the western side of the Cascade Range in Oregon, soil mass movements occur much more frequently in areas of predominantly altered volcaniclastic rocks (tuffs and breccias) at elevations below 900-1000 m than in areas comprised of unaltered lava flows (basalt and andesite) at higher elevations (Dyrness 1967, Swanson and Dyrness 1975). Soil mass movement over a 25-year period in the unstable volcaniclastic terrain was 2.8 times higher for deforested areas compared to forested sites, indicating the stabilizing effect of vegetation on this weak rock. In both the Cascade Range in Oregon and the northern California Coast Range, stability problems associated with weak rocks are exacerbated by crustal deformation and unfavorable geologic structure.

The influence of rock structures (bedding planes, folds, joints, faults, etc.) is an important factor in the stability of natural hillslopes. Downslope dipping planes between certain sedimentary and volcanic rocks of different competence or alteration, as well as joints and fractures oriented in the same direction, may likely impede vertical infiltration and root penetration, thus acting as potential failure planes. Horizontal or cross-dip bedding may provide natural buttresses that may actually increase the stability of slopes (Swanston 1978). Fault zones often contain fractured, crushed, or partly metamorphosed rocks resulting from stress relief and intrusion of igneous or ultramafic rocks during geologic uplift. The inherent geologic weakness of these zones is further enhanced by deep percolation of water into the bedrock and subsequent chemical weathering of mantle material into clay-rich soil which is susceptible to slump-earthflow type of failures.

Other geologic situations that are susceptible to soil mass movement include most shallow soil mantles over relatively impermeable rocks on steep slopes and resistant volcanic flow rocks overlying clay-rich rocks. Crystalline igneous and metamorphic rocks and competent sedimentary rocks often occur in mountainous terrain and, for these situations, overlying soils may be poorly attached to bedrock. Translational sliding of the whole soil mantle over the underlying rock in debris slides-debris avalanches is a common feature of such areas (for example, British Columbia, O'Loughlin 1972; coastal Alaska, Swanston 1974; the Appalachians, Bogucki 1976, Eschner and Patric 1982, Woodruff 1971; and Adirondacks, Bogucki 1977). Bedding and jointing in hard sedimentary rocks may permit better attachment of soil to the underlying rocks than that frequently found with more massive igneous and metamorphic rocks. Clay layers located at the soil-bedrock interface may provide an especially susceptible surface for sliding-type failures (O'Loughlin and Pearce 1976). In areas where resistant flow rocks (for example, basalt) overlie incompetent, clay-rich, volcaniclastic rocks, large-scale soil creep, earthflows and slumps can develop. Examples of such situations include soil creep and slump-earthflows along the Columbia Gorge in Oregon and Washington (Palmer 1977), along the western side of the Cascade Range of southern Oregon (Swanson and Swanston 1977), and along the eastern side of the Oregon Coast Range (Beaulieu 1974, Swanston 1978). Slumps and earthflows occurring in such terrain typically have steep headwall scarps (Swanson and James 1975).

Shallow landslides are common in western North America where mountains have undergone natural steepening by tectonic uplift and glaciation. Although slope gradient can be closely related to shallow mass movement processes in certain areas (for example, Ballard and Willington 1975, Lohnes and Handy 1968, Swanston 1974), it is difficult to make generalizations based on these localized relationships because of other complicating geologic, climatic, and land-use factors. The concept of a threshold angle of slope steepness is largely based on observations of shallow landslides on particular soil-rock types and has worked well as a predictive tool for debris avalanche risk evaluation in specific areas. In hillslopes with developing (for example, recently glaciated) or changing (for example, active soil creep) soil mantles, identification of high-risk landslide areas must take into account soil mantle thickness as well as rock and soil properties and slope steepness.

A lower limit of slope gradient for various soil mass movements is difficult to specify and wide variations in typical gradients for these processes are apparent (fig. 1). Although generalizations are difficult to make, many slopes over 25° are probably subject to rapid soil mass movement, especially if the soil mantle is poorly bound to the underlying rocks (Sidle and others, in press). Most slopes over 35° are subject to soil mass movement (if soil is present). Slower processes, such as slumps and earthflows, initiate on slopes as gentle as 4-20°. Soil creep has been measured on slopes as gentle as 1.3° (Finlayson 1981); however, certain sites may require gradients as steep as 25° before measurable creep occurs (Burroughs and others 1976). Specialized failures, such as lateral spreads or flow in quick clays, can occur on nearly level slopes.

Slope Shape

Slope shape is important in determining the distribution of soil water in unstable landscapes. Convex slopes disperse subsurface water and tend to be more stable than concave slopes which concentrate subsurface water into small areas of the slope. The frequent association of shallow-rapid landslides with hillslope depressions and V-notch gullies is, therefore, not surprising. Following failure, these depressions gradually fill in by localized sloughing around the headwall, soil creep, and movement of organic debris and surficial material from above (Dietrich and Dunne 1978, Lehre 1981). Soil in hillslope depressions, consequently, may often be much thicker than that in intervening minor ridges, increasing the likelihood of additional failure. Repetition of failure occurs when the depressions become sufficiently overloaded with mineral and organic debris coupled with an episodic storm or snowmelt. The frequency of intermittent failure in these depressions is on the order of tens to hundreds of years depending on rates of fill in and process linkages involved at particular sites.

SOIL PROPERTIES

Engineering Properties Of Soils

Soil shear strength (s), which quantitatively describes the resistance of a soil to failure, is generally considered to be a function of normal stress on the slip surface (p), cohesion (c'), and internal angle of friction (Ø'). Normal stress is influenced by the unit weight or density of the soil at field moisture content, soil depth, and slope gradient. Pore water pressure (μ) at the failure surface decreases the normal stress to an effective normal stress (p') by acting as a buoyant force. Infiltrating water can generate unstable conditions on hillslopes by increasing the weight of the soil mantle and by eventually increasing pore water pressures.

Cohesion is directly related to the plastic nature of soils. Noncohesive soils are essentially nonplastic. Cohesive soils have high clay content and are characteristic of deep-seated soil creep and slump-earthflow mass movements. Cohesion in these fine-grained soils is a function of moisture content. Cohesion increases slightly with increasing moisture and then decreases rapidly as moisture content is further increased. The point at which cohesive forces are greatest generally corresponds to the minimum moisture content at which the soil can be deformed without rupture (that is, the plastic limit). Rogers and Selby (1980) indicate that the cohesion component of two landslide soils (clay and silty clay textures) decreased 18 and 70 percent respectively, following saturation. In field soils, cohesion is supplemented by the contribution of rooting strength (c_r); the sum of these is called total cohesion ($c + c_r$). Aggregation in the soil matrix reflects cohesive forces, but aggregation may increase interlocking, which increases the friction angle (Ø).

Internal angle of friction (Ø) represents the degree of interlocking of individual grains or aggregates and is influenced by the shape, roundness, size, and packing arrangement of these particles. Angular particles have a larger Ø than rounded particles because of their greater interlocking capabilities. True cohesionless soils, such as sands, form a single-grained structure with their shear strength mainly dependent on intergranular friction and on grain interlocking. Aggregated soils may exhibit cohesionless behavior in that aggregates act as individual grains. Yee and Harr (1977) found that aggregation in two essentially cohesionless soils was largely responsible for their relatively high Ø values (40-41°). Compaction of soil materials increases Ø by rearranging particles into a tighter packing configuration.

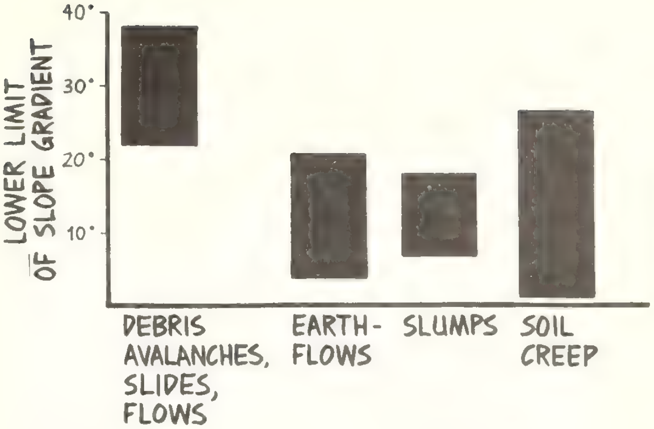

Figure 1.--Lower limit of slope gradient, generally measured in a representative portion of the scouring or active movement zone, for various soil mass movements (after Sidle and others 1984).

Chemical/Mineralogical Properties

The influence of clay mineralogy on certain physical and engineering soil properties is an important consideration in the stability of cohesive soils. However, unlike certain physical parameters (for example, subsurface water, slope gradient), mineralogical and chemical properties are normally not solely responsible for slope failure, but rather act synergistically with other destabilizing factors.

Because of their swelling characteristics, smectite clays (for example, montmorillonite, beidellite) are associated with a number of mass soil movement landforms. Smectites have been found to be major constituents in deep-seated mass soil movements, such as earthflows in the Cascade Range in Oregon (Paeth and others 1971, Taskey 1977) and southwestern Pennsylvania (Ciolkosz and others 1979) and deep soil creep in California (Fleming and Johnson 1975). Soils high in montmorillonite have been associated with bentonite debris flows in northern Alaska (Anderson and others 1969) and landslides in Wyoming (Booy and Kerr 1973) and Montana (Klages and Hsieh 1975).

Kaolinite, a nonswelling clay, tends to be a component of more stable soils along the western side of the Cascade Range in Oregon (Paeth and others 1971, Taskey 1977) and in California (Borchardt 1976). Halloysite, a clay with similar mineralogy to kaolinite, has a tubular structure that allows the incorporation of interlayer water into the clay lattice. Unstable slopes have been associated with the hydrated form of halloysite in the Cascade Range in Oregon (Taskey 1977) and Oregon Coast Range (Istok and Harward 1982).

The hydrous mica (for example, illite, vermiculite) and smectite clays both tend to occur in the so-called quick clays of Canada and Scandinavia (Kerr 1963, Rosenquist 1953). Quick clay behavior involves a sudden structural alteration from a fairly stable, brittle solid to a liquid of negligible strength. Quick clays can suddenly turn to liquid when vibrated by such energy sources as an earthquake or blasting. One explanation of this rapid loss of strength is the extensive leaching of salt water cations, which ultimately reduces interparticle bonding in the quick clay matrix (Kaze and Moum 1973, Rosenquist 1953). Many quick clays were deposited in marine or brackish environments and thus developed a dispersed structure rich in sodium and other cations (Yatsu 1967). As these areas rose above sea level following glaciation, some adsorbed cations were leached out of the clays decreasing the ionic strength and changing the chemistry of the pore water. The lower cation concentration within the soil matrix coupled with naturally high water content (often exceeding the liquid limit), makes quick clays highly unstable (Eden and Mitchell 1970). Smalley (1976) emphasizes that quick clay behavior can also occur in soils composed of the primary mineral particles (as opposed to true clays), in which case the rapid loss of strength may be related more to fracturing of interparticle cementing material (for example, iron oxides, calcium carbonate, silica) during disruptions than to the long-term cation leaching phenomena observed in marine clays. Disruption of cementation appears to be a greater cause of liquefaction in the Canadian quick clays than in the Scandinavian materials (Eden and Mitchell 1970, Smalley 1976).

Earthflows in the Cascade Range and Coast Range of Oregon have been related to the presence of amorphous clays (Istok and Harward 1982, Taskey and others 1978). The instability of these amorphous clays was partially attributed to their high water-holding capacities. The water could presumably be released following disturbance, accounting for the fluid behavior of earthflows.

HYDROLOGIC FACTORS

Factors influencing Groundwater Levels

Hydrologic processes influencing the stability of hillslopes are largely dependent upon the incident rainfall or snowmelt regime, the rate of water entry or recharge into the soil mantle, the transmission rate of water within the soil mantle, and evapotranspiration. The general rainfall or snowmelt rates in undisturbed forested areas rarely generate extensive overland flow over large areas. Saturated or nearly saturated soils in valley bottoms or in isolated hillside locations may experience overland flow during storms. In general, however, the dominant mechanism of downslope water movement is by transmission within the soil mantle. The relative rates of recharge, transmission, and evapotranspiration determine the transient level of groundwater occurring in hillslope soils and thus influence their stability during rainstorms or snowmelt.

Recharge of soil water is the result of water entering the soil and is influenced by vegetative cover, cultural practices, and landscape shape, as well as soil physical properties affecting water movement. Soil water recharge can be greatly influenced by soil layering or the presence of a shallow water table. Downward progress of the wetting front may be greatly impeded when it encounters a layer of considerably lower permeability or other changes in texture or structure. The same effect occurs when infiltrating water reaches a perched water table. Tension cracks, which develop around the headwalls and flanks of potential slope failures, provide a rapid recharge route for water into the soil mantle. Vegetation and ground cover generally enhance soil water recharge. Forest soils typically have high recharge rates because of their thick, permeable organic horizons. Cultural practices such as road building, logging, and burning can significantly reduce soil water recharge.

The discharge rate of water from unstable soil mantles is probably the most significant hydrologic factor affecting soil mass movement. If subsurface flow rate is less than infiltrating rainfall or snowmelt rates for extended periods of time, a perched goundwater table will form within the soil mantle. The height and persistence of the perched water table depends largely on rainfall or snowmelt intensity and duration, infiltration rate at the site, slope gradient, and subsurface flow rate within the soil mantle. Because the infiltration rate often does not limit recharge of unstable slopes, the subsurface flow rate becomes the controlling hydrologic variable during many rainfall or snowmelt periods.

Large, interconnected soil pores (that is, macropores, soil pipes) provide important passageways for transport of subsurface water in hillslope soil mantles (Jones 1971, Whipkey 1965). Although piping networks are believed to be somewhat interconnected over large areas (Pond 1971), small breaks in this network would create potential sites of extensive positive pore water pressure buildup as the surrounding soil would have a much lower permeability. Tsukamoto and others (1982) cited pipeflow as a primary contributing factor in debris slide initiation in small hillslope basins in Japan. Extensive but discontinuous piping networks have been found in earthflow landforms and are believed to accelerate movement by allowing excessive pore water pressures to build up (Blong and Dunkerly

1976). In such slow mass movements, it is conceivable that the size and extent of pipes, as well as their degree of interconnection, could change over short periods of time.

Evapotranspiration influences soil water recharge and subsurface flow and, thus, may affect slope stability through either transpiration or interception (depending on vegetative characteristics), seasonal distribution of precipitation, and timing of transpiration relative to precipitation. Deciduous vegetation in climates with fall or winter rainfall maxima will have the least stabilizing influence upon the soil mantle because interception and transpiration are minimal during the extended periods of recharge and saturation. In similar climates evaporation of intercepted rainfall from conifer canopies is one of the few pathways of diverting incident rainfall away from unstable slopes. Colder, higher, snowfall areas, where soil mass movements are intiated by snowmelt, may experience similar ameliorative effects by long-term evaporation of snow from conifer canopies.

Because most shallow rapid mass movements occur during extended rainfall or snowmelt periods, evapotranspiration is unlikely to be a major controlling factor except during the first large rainstorm of the season (Megahan 1983). Increased evapotranspiration may help to reduce the movement rate of deep-seated soil creep and earthflows. Conifers on slopes affected by these movement types will have beneficial effect, compared to other types of vegetation, by extending the period of low soil moisture, by drying the soil to a greater depth during low-rainfall seasons than would occur with shallow-rooted vegetation, and by delaying and extending the period during which recharge takes place.

Groundwater-Slope Stability Relationships

Although implicit relationships have been developed between storm characteristics and landslide occurrence in certain areas of North America (for example, Nielsen and others 1976), only a few studies have investigated the response of shallow grounwater in unstable slopes during storms. Megahan (1983) related peak piezometric rise in two small drainages in the Idaho batholith to snowmelt rate. Nearly total saturation of the soil mantle was reached during a high snowmelt season. Pierson (1980) found complete saturation of the oil mantle along the lower axes of several hillslope depressions in the Oregon Coast Range during a winter storm with an estimated return period of 3 to 4 years. Piezometric head decreased in the upslope direction at most sites. Harr (1977) observed completely saturated conditions at the foot of slightly convex, unstable slopes during moderate winter storms (return periods <1.5 years) in the Cascade Range in Oregon. Isolated regions of partial saturation at the surface soil-subsoil boundary were detected in midslope and upslope locations. Sidle and Swanston (1981) and Sidle (1982) found artesian conditions occurring during major storms at various slope positions in the trough of a hillslope depression. Data from these heavily instrumented depressions suggest that in such areas where convergent flow dominates, groundwater peaks may occur simultaneously in the upper and lower portions of the slope, although maximum groundwater peaks may dissipate more quickly in the upper slope locations (fig. 2). In calculating soil shear strength for such sites, the most important hydrologic parameter is the maximum piezometric response (even if only shortterm). Data for shallow soils (<1 m) suggest that nearly saturated to artesian conditions may be necessary to induce slope failure (O'Loughlin and Pearce 1976; Sidle 1982, Sidle and Swanston 1981, 1982).

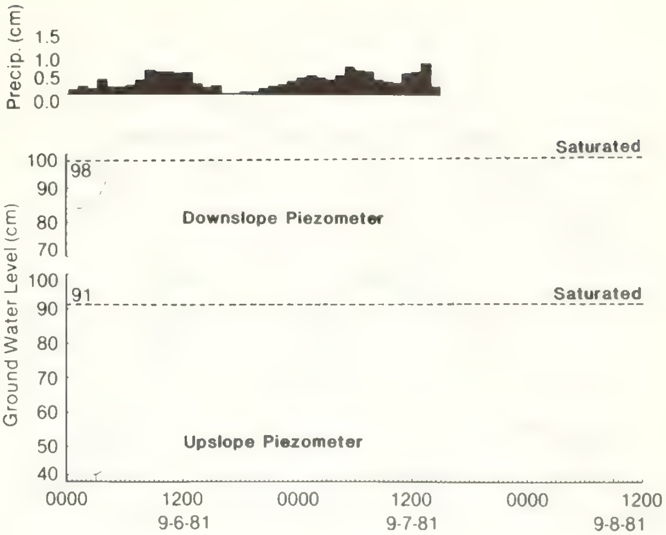

Figure 2.--Groundwater response in two portions of an unstable hillslope depression during a storm of moderate intensity, Kennel Creek, Chichagof Island, Alaska.

Shallow-rapid soil mass movements generally respond to individual storm or snowmelt events, and deep-seated earthflows and soil creep are more influenced by seasonal rainfall,. Studies in the Pacific Northwest and northern California indicate that soil creep occurs at rates <1 to >100 mm/yr with movement concentrated during the rainy season (Swanson and Swanston 1977; Swanston 1981). Movement of deep-seated failures is generally slow early in the wet season, while the soil mantle is recharging, and later becomes more responsive to rainfall inputs (Swanson and Swanston 1977).

VEGETATIVE FACTORS

Influence Of Roots On Slope Stability

Plant root systems contribute to the stability of hillslopes in several ways. Roots add strength to the soil by vertically anchoring through the soil mantle into fractured bedrock or other more stable substrate. This mechanism is only effective in stabilizing relatively thin soils (that is, <1 m), such as those found on steep, dissected slopes of coastal British Columbia and Alaska. Dense networks of medium- and small-sized roots reinforce the upper soil layer so that it acts as a membrane to provide lateral strength and increased slope stability (O'Loughlin 1981). The combined effect of this "membrane strength" and vertical anchoring is evidenced by the location of landslide planes just beneath the zone of dense root networks on deforested slopes. Swanson and Swanston (1977) suggest lateral root reinforcing across planes of weakness (for example, headwalls and tension cracks around earthflows) may also be important in providing stability to deeper soils prone to creep and earthflow movement. Larger structural roots in the vicinity of individual trees can provide buttressing or soil arching action between trunks, depending upon tree spacing (Gray and Megahan 1981). This buttressing mechanism is only important in stabilizing thin soil mantles prone to debris slides and avalanches.

Effect Of Root Deterioration

The deterioration of tree roots following timber harvesting is believed to be an important mechanism reducing the stability of steep slopes with shallow soils. Studies in various areas have shown an increased frequency of shallow landslides occurring 3 to 10 years after logging; the period of minimum stability during residual root decay and subsequent regeneration (Bishop and Stevens 1964, Megahan and others 1978). Following this susceptible period of minimum soil strength, regeneration generally improves the stability of the slope (fig. 3).

When roots fail during landsliding they more commonly fail in tension rather than in shear (Gray and Megahan 1981, O'Loughlin and others 1982). Studies indicate that root tensile strength following tree cutting declines in an exponential manner over a period of several years (Burroughs and Thomas 1977, O'Loughlin and Watson 1979). Ziemer and Swanston (1978) found an increase in average root strength of Sitka spruce and western hemlock 4 to 6 years after tree removal associated with residual, strong, resinous roots. This would not increase the overall soil strength, however, because most nonresinuous roots had completely decayed.

The type of vegetation occupying a hillslope can influence the relative rooting contribution to soil strength. In general, root strength tests indicate that coastal Douglas-fir and western red cedar roots are stonger than western hemlock roots, which in turn are stronger than Sitka spruce roots. Living conifer roots tend to be weaker than similar-sized hardwood roots. Studies indicate that certain hardwood shrubs that are often suppressed or killed by herbicides or slash burning following logging, have rooting systems of comparable strength to overstory species (Ziemer 1981, Ziemer and Swanston 1977).

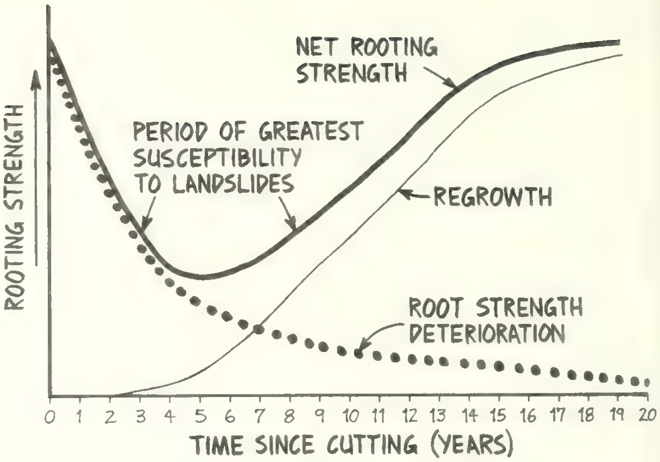

Figure 3.—Hypotnetical curves indicating root strength deterioration following timber harvesting, rooting strength of regenerating site vegetation, and net rooting strength. Period of minimum rooting strength is noted approximately 3-8 years following logging.

Root systems of different species also decay at different rates following vegetation removal. Burroughs and Thomas (1977) found that although coastal Douglas-fir roots are stronger than those of the Rocky Mountain variety, they decay much faster after cutting. Sitka spruce roots decay more rapidly than do hemlock roots (Ziemer and Swanston 1977). The rate of root decay following timber harvesting, as well as the amount of shrub cover left on the site, can greatly modify the timing and extent of the minimum stability period shown in figure 3.

SEISMICITY

In seismically active regions, moderate to large magnitude earthquakes have generated sufficient ground motion to initiate failures on slopes that exist in an already delicate state of balance. Some of the largest and most devastating landslides in recent history have been triggered by major earthquakes. The effectiveness of earthquakes in triggering landslides and the distance at which earthquakes can cause failures depends on many factors including the stability of the potential slide masses, vegetation, land use, the orientation of potential failures in relation to the earthquake epicenter, and direction of seismic wave propagation, earthquake magnitude, focal depth, seismic wave attenuation, and aftershock distribution (Voight and Pariseau 1978). In summarizing landslide data from 40 worldwide earthquakes, Keefer (in press) indicates that the area affected by landslides is directly proportional to earthquake magnitude, increasing from 0 km^2 at M = 4.0 to approximately 500,000 km^2 at M = 9.2. Rock falls, rock slides, soil falls, and disrupted soil slides can be triggered by the weakest seismic activity. Deep-seated slumps and earthflows are generally initiated by stronger (and probably longer duration) seismic activity.

Lateral spreads, debris flows, and subaqueous landslides require the greatest earthquake magnitudes.

SUMMARY

Many of the natural factors influencing the stability of slopes may act synergistically to initiate or accelerate soil mass movements. For example, steep slopes with thin, cohesionless soils, underlain by impermeable rock or compact till may exist in a state of marginal stability until a major storm generates extensive pore water pressures within the soil mantle. The subsequent failure of such sites, typical of shallow-rapid failures in the coastal Pacific Northwest, is a testimony to the interaction of unfavorable geomorphic, soil, and hydrologic conditions. In other similar areas, the triggering mechanism for slope failure may be a moderate-sized earthquake.

The influence of vegetation on slope stability is most apparent in situations where vegetative cover has been drastically modified (that is, clearcutting, conversion of forest or brush land to pasture and crop land). In conjunction with natural factors such as extended rainfall or earthquakes, other land management practices predispose marginally stable hillslopes to landslides. Roadbuilding decreases slope stability by mechanically steepening or overloading slopes, undercutting unstable toeslopes, and concentrating drainage water onto unstable slopes. Residential development on forested or brushland hillslopes causes similar instability problems, with the additional destabilizing factor of widespread vegetation removal.

Responsible land management must evaluate the inherent slope stability risk associated with these intensive and extensive land uses. Risk analysis involves consideration of both natural and land use factors predisposing slopes to failure. Some factors, such as soil strength and slope gradient, can be measured or estimated. Effect of vegetation removal or conversion can be estimated from empirical studies of rooting strength decay. Other factors, such as groundwater, are dependent on probabilistic events. Thus, certain risk analyses (that is, for shallow, rapid failures) must not only estimate or measure natural or management-related factors, but also superimpose the probability of a threshold storm occurring.

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LANDSLIDE DAMAGE TO THE FOREST ENVIRONMENT

George W. Brown

ABSTRACT: Damage from landslides is a central issue facing land managers today. Landslides may damage site productivity, water quality, anadromous fish habitat, and roads and structures, but it is often difficult to determine the extent and duration of the damage. The reason is that landslide impacts vary widely depending on location of the landslide with respect to valued resources, time, and size of the event. Damage is almost impossible to predict and warrants additional research, especially in today's political environment.

INTRODUCTION

Damage from landslides is a central issue facing land managers today. What has been damaged, by how much, and by whom are important questions many of you have had to address. And if you have become involved in a controversy about landslides, you know that these questions are not easy to answer, especially those that attempt to separate natural landslides from those caused by human activities. Thus, before we examine specific ways in which landslides produce environmental damage, some general points about such damage are in order.

1. Webster defines damage as "loss resulting from injury." Landslides produce noticeable changes in the forest environment, but "losses" and "injury" are often very difficult to quantify. For example, subtle changes in the quality of anadromous fish habitat may require special study to detect.
2. Time is an important variable when considering damage. In the shortterm, landslides can destroy bridges, roads, home sites, and fish habitat. In the longterm or geologic time scale, landslides may be viewed as a more normal part of the earth's natural land-forming process or even as a positive contribution to the environment. Today's landslide material will become gravel or beach sand 1,200 years hence.
3. Damage caused by landslides is usually a function of the size and location of the event. Small landslides in areas far removed from human habitation or important spawning sites may produce no "loss" or "injury." Landslide numbers or frequency are not necessarily good indicators of damage.
4. In a legal sense, damage and negligence are separate issues. Parties damaged by landslides originating on an owner's land upstream may petition the court for reparation regardless of findings of negligence. Negligent landowners are subject to additional punative damages. In this paper, I will deal only with the damages that landslides produce. Landowner action that may constitute negligence is beyond the scope of my assignment.

I will address four physical aspects of the environment that may be damaged by landslides: site productivity, water quality, anadromous fish habitat, and roads and structures. No attempt will be made to distinguish the effects of natural and human-caused landslides.

SITE PRODUCTIVITY

Little documentation has been done on how

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landslides affect site productivity, probably because landslides usually occupy less than 1 percent of the landscape, even in highly unstable areas where clearcutting has been practiced.

Trees grow slower on landslide tracks than on adjacent, undisturbed soil. In the Cascade Range in Oregon, Miles (1983) examined 25 landslide tracks ranging from 6 to 28 years old and compared tree growth, stocking levels, and vegetative cover on them and on adjacent clearcut areas. He found that by 18 years, height growth of Douglas-fir seedlings was reduced by 38 percent, stocking by 25 percent, and volume by 40 percent on the landslide tracks. About 30 percent of the landslide area was nonstockable. Vegetative cover averaged about 51 percent on the landslide areas, but it ranged from 7 to 88 percent. The variability was so great that it masked any predictable recovery trends.

In southeast Alaska, Adams[1] conducted a similar study on recent tracks left by debris avalanches. He found that soils in the tracks had fewer rooting sites, lower nutrient status, and higher bulk densities than would be expected in undisturbed forest soils. Adams' results help explain the growth reductions reported by Miles for trees growing on landslide tracks.

Thus, trees and other vegetation grow more poorly on landslide tracks than on adjacent soils, but so little work has been done on this topic that prediction of the overall impact of landslides on site productivity is impossible. Fortunately, landslides usually occupy a very small percentage of the landscape. Where they are more frequent, their overall impact on forest productivity could become significant, particularly if site recovery were slow.

WATER QUALITY

Landslides may increase turbidity and sedimentation in streams, rivers, and estuaries. These increases, in turn, reduce the quality of water for aquatic organisms and human consumption. Large landslides scour channel banks and destroy streamside vegetation, thereby exposing previously shaded stream channels to direct sunlight and perhaps increasing water temperature.

The key factor determining the impact of landslides on turbidity is whether slide debris reaches a channel where there is intermittent or perennial streamflow. In Pacific Northwest coastal streams, the turbidity produced by small landslides may be masked by the normally high variation in turbidity or suspended sediment. Furthermore, not all landslides or the sediment they produce reach channels in which water quality is critical for humans or aquatic organisms. Kethcheson and Froehlich (1978) inventoried about 40 slope failures in clearcuttings in the Oregon Coast Range and found that most small debris slides traveled only a short distance; none reached a channel. Other failures scoured first- and second-order channels, but none reached fish-bearing streams.

Such events could, nevertheless, affect sediment and turbidity in streams and estuaries because the scoured channels and debris deposits are sources of sediment immediately available for subsequent erosion. For example, road-related landslides doubled the predicted annual sediment yield for 1 year from a coastal watershed (Brown and Krygier 1971) and increased the mean concentration of suspended sediment during winter storms from less than 100 to nearly 4,000 parts per million in a Cascade Range watershed (Fredriksen 1970). In both examples, turbidity exceeded Oregon's water quality standard for the short period of high runoff during and immediately following storms. An interesting footnote in the coastal study is that coho and cutthroat populations were not affected by this short-term increase in sediment.

Many urban areas in the Pacific Northwest obtain their domestic water from forested watersheds, as do many rural families. Often, chlorination is the only treatment given this water. Normally, this water is so clear that sophisticated filtration systems are not needed. In such circumstances, any suspended sediment caused by landslides will enter the distribution system and consumers will be forced to use turbid water or find alternative sources. Lawsuits are a likely byproduct.

Fortunately, turbidity produced by landslides is usually short-lived in forest streams. Even in the most extreme events, turbidity usually declines rapidly after rainfall ceases. An important exception is the turbidity resulting from colloidal suspension of clays and runoff in a reservoir. In such cases, water may remain turbid for days or weeks.

Thus, water quality can decline because of landslides. The magnitude and duration of the impact depends upon the size of the slide and how far it travels, whether it enters a stream channel, and the type of soil material it contains. Again, the number of variables involved and the naturally high variability of sediment transported in mountain streams make prediction of damage to water quality very difficult.

ANADROMOUS FISH HABITAT

Landslides have had their greatest impact on forest management by inflicting damage on fish habitat. Directly resulting from such damages, either real or perceived, are recent lawsuits against the USDA Forest Service and changes in the Oregon Forest Practices Rules. In extreme cases, damage is obvious because spawning gravel is scoured to bedrock or buried beneath mud and debris. In other cases, damage to habitat from landslides may be very difficult to detect and quantify. In all cases, damage to habitat and subsequent impact on fish populations is almost impossible to predict.

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[1] Personal communication, Paul Adams, Dept. of Forest Engineering, Oregon State University, Corvallis.

Previously cited data from Ketcheson and Froehlich (1978) demonstrate that not all slides reach channels and that many of those that do are confined in the upper reaches above channels where fish live or spawn. The good news in these findings is that many of the slides that occur, particularly small ones, may never cause the type of catastrophic damage to channels that many people predicted. The bad news for managers is that much of the habitat damage that may occur from landslides of this type will take a lot of careful study to detect. For example, the fine sediments produced by such erosion are not always incorporated directly into spawning gravels. Sometimes these sediments rapidly wash through the streams and are deposited in lower river reaches or in estuaries. Incorporation of sediment into spawning gravels is such a complex process that relationships have not yet been defined for linking the quantity of sediment produced to the productivity of a stream reach or spawning site. Part of the complexity stems from the fact that the stream will work on landslide deposits and eventually produce usable habitat. Furthermore, fish have an ability to modify their spawning environment and cleanse spawning gravels of intruded sediment. Chinook, for example, can change gravel that is 40 percent fines to 15 percent fines by digging a redd.

Estuarine sedimentation is also very complex, but it has the potential for significant damage. Most of the commercial fish and shellfish along the coast spend a portion of their life cycle in the estuary and are highly dependent on the top 2 to 30 cm of the estuary bottom for food. Sedimentation can upset their food chain, though to what degree is uncertain.

Also uncertain is how fast coarse material from landslides move downstream or what effect they have on quality of spawning gravel. We know that coarse materials move more slowly than fines and that their greatest impact may be on channel morphology. Altering channel characteristics may, in turn, have an important effect on the amount and quality of available rearing habitat. In some cases, the effect of introduced coarse material is very negative, but in streams that are gravel-poor, coarse material from landslides may enhance the quality of spawning gravel. In other cases, the change in stream morphology may change the mix of species, but not the biomass of fish. For example, more riffles and less pools would favor chinook and steelhead at the expense of coho. Both cases are good examples of the difficulty in making damage assessments.

Large landslides from clearcuttings or roads may greatly alter anadromous fish habitat. But many of the small slides more common to forested terrain either do not reach streams or are confined in upper reaches above fish habitat. The impact, if any, may be very difficult to detect, and in some cases, may even be positive. Estuarine habitat may be as important to fish as upstream sites, but understanding of the estuary system is so limited that assessing and predicting damage to it is nearly impossible. Landslides can damage anadromous fish habitat, but the relationships are often very complex. Managers must recognize that factors such as characteristics of the landslide, topography and the affected stream channel combine to produce a given impact. Research is a long way from unravelling these complex relationships. At least we now know that simple correlations between road mileage or acres harvested and stream damage are not useful as predictive tools.

ROADS AND STRUCTURES

Landslides frequently damage roads and bridges in the forest, and large landslides may even reach valleys where people live and farm. Damage to structures is often easily quantifiable in economic terms. Rothacher and Glazebrook (1968) noted that roads were involved in over 60 percent of all damage reports made by national forests after the 1964 floods and that most of this damage was related to landslides. Total damage to roads and bridges from these floods was $12,500,000 (in 1968 dollars). Other damages are less easily quantified. For example, losses of human life, of fertile farm land buried under debris, and of access to a road system out of service are very difficult to express economically. But regardless of how difficult it is to quantify such damages to the social fabric, they are among the most visable impacts of landslides.

The most important aspect of such damage is that it is likely to increase from both natural and human caused events. Road systems, bridges, and home sites are all increasing in the forest. The Forest Service adds about 6400 km. of new road each year to its 496,000 km. system. Other agencies and forest industries also continue to expand their transportation networks; much of the new construction is in the most difficult terrain. Continued expansion of these large networks of forest roads means that maintenance problems and costs are also increasing.

Residential encroachment on land heretofore considered as forest or agricultural fringe is a growing problem for forest managers. A typical tenure pattern in the West is federal or industrial ownership of the hillslopes with the valley bottoms owned by small farmers or ranchers. Valley lands once dedicated to agriculture are increasingly subject to subdivision and ownership by part-time ranchers who then establish homesites. Such homesites are typically on a bench or knoll at the mouth of a draw; the knoll provides elevation above the valley floor and, usually, a small creek for domestic water. This ideal location is, unfortunately, likely to be a debris fan formed by old landslides. Any subsequent landslide, natural or otherwise, may jeopardize the homeowner or, at a minimum, the water supply. Legal actions to recover damages are likely to follow. And even natural slides from timbered areas may figure in legal suits if property damage results. While education and more sophisticated zoning are probably the long-term solutions to these problems, managers must be sensitive to the short-run impacts and be prepared to use special, more costly, road construction and harvesting techniques for lands upslope from residential property.

Damages to roads and structures are highly visable, fairly easy to quantify, and may result in legal action by damaged parties. Furthermore, such damage is likely to climb as roads are pushed into increasingly difficult terrain and as residential development continues on forest margins. Because of the hazards involved, managers may find it increasingly necessary to use more expensive types of road construction.

CONCLUSIONS

Environmental damage is a central issue in the present controversy about landslides and forest practices. It is also one of the most complex parts of the controversy because losses are often difficult to quantify and almost impossible to predict. Those who manage our national forests must realize that research is a long way from developing the quantitative relationships needed to help relate harvesting and road construction to landslides and thence to environmental damage or loss. And the answers are not likely to be forthcoming until a national commitment is made to determine those relationships.

Do landslides produce environmental damage? They certainly do. But predicting or quantifying how much, where it occurs, and how long it lasts is often beyond our present capability.

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PITFALLS IN THE STRICT RELIANCE ON EXPERT OPINION IN ASSESSING SLOPE STABILITY HAZARD

James A. McNutt and Dale McGreer

Abstract: A Bayesian/Delphi analysis of slope stability hazards was performed based on intensive and statistically structured surveys of expert opinions from 35 soils, hydrology and geology specialists. While theoretically sound, and with potential for practical application, the process revealed several potential weaknesses of relying on expert opinion. Major problems were associated with the natural tendency for experts to dwell on sites which failed, rather than those which did not. Additionally, experts had difficulties conceptualizing how seemingly small numerical estimates of probability of failure can translate into very large numbers of failures when applied to large land areas and through time. The authors conclude that if these tendencies exist during a structured research interview, they are also likely to occur while assessing hazards for planning or during field hazard assessments.

INTRODUCTION

Contrary to what we'd like to believe,...most invention comes from the "wrong" person in the "wrong" place in the "wrong" specialty at the "wrong" time, not to mention in conjunction with the "wrong" problem.

This paraphrase of Thomas J. Peters, (1983), author of In Search of Excellence, in his review of the mythology of innovation is startlingly counter-intuitive. However, historical studies of scientific discovery clearly illustrate that this is indeed the way of the world. Thomas Kuhn (1970), in his Structure of Scientific Revolution, documents that throughout time, groups of trained experts have consistently focused so narrowly that they fail to see or accept major new discoveries.

Galileo, a non-astronomer, is now famous for his astronomical observations; Louis Pasteur, a chemist, is now acclaimed as the father of modern day sterilization theories for the medical profession. Yet, while both of these gentlemen made brilliant advances outside their areas of specialty, the specialists inside those areas could not or would not accept these discoveries.

And the problem continues today. Jewkes, Sawers and Stillerman (1969), in their The Sources of Invention reviewed nearly 60 major 20th century inventions, of which at least 80% were discovered by the wrong people in the wrong place. For example, Kodachrome film was invented by two musicians, and a watchmaker discovered the process for continuous casting of steel.

Also important is Thomas Kuhn's observation, that even when new discoveries are accepted by experts, poor vision about the simplest

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applications with the most potential often lag the initial acceptance by a quarter of a century or more. For example, Thomas Alva Edison observed that the primary application of incandescent lighting would be aboard ocean going vessels where the then existing open flame gas or oil burning lights were exceedingly hazardous. Similarly, the British Secretary of War, a highly trained military tactician, noted in 1910 that "we do not consider that the aeroplane will be of any use for war purposes."

THE PITFALLS

This may seem like a strange way to introduce slope stability hazard analysis. However, a broad review of a slope stability research project we undertook in the late 1970's (McNutt, 1976; McNutt and McGreer, 1981) reveals several pitfalls mentioned in this introduction. These pitfalls must be taken into account, both by the specialists who are charged with advancing the technology of slope stablity hazard analysis, and by the resource managers who must manage lands, hazards, and resources. Our research indicated that:

a) Many slope stability experts have expertise which is narrowly focused to given hydrological and geological provinces.

b) Because of narrow focus, many experts, at least intially, have a difficult time understanding and accepting new approaches which could lead to practical and beneficial applications.

c) Experts are often so close to the problems at hand that they frequently fail to recognize the real world potential of new analytical methods, especially if these methods are developed external to their particular specialty.

d) Slope stability experts' focus is primarily directed at the study of actual slope failure events and the associated site and climatic conditions. As a consequence of this narrow focus, the experts often fail to extrapolate their knowledge correctly to the forest as a whole, in changing conditions over long time horizons.

THE PROBLEM

The major challenge facing slope stability specialists is to develop reliable techniques for assessing slope stability hazards under any set of specific conditions. This requires identification of cause and effect relationships between variables which are numerous, interrelated, and multi-dimensioned. Dealing with these relationships is a monumental task. Natural variations of slope, soil, geologic, hydrologic and vegetative variables, and man initiated activities are tremendous and collectively generate literally an infinite number of unique conditions.

Available historical data bases which would allow correlation of cause and effect relationships are inconsistently structured. Consequently they are only marginally useful for developing models that predict slope stability hazards. New quantitative knowledge of slope stability experts is quite good and growing every year. In essence, these circumstances "promote" the classic conditions for application of predictive techniques based on Bayesian/Delphi probability theories: the approach we used in our research.

Simply put, Bayesian/Delphi theories applied to slope stability hazard analysis convert experts' qualitative opinions into quantitative estimates of how often different variables, taken one at a time, are associated with a slope failure event (Delphi techniques). For slope stability problems, this process is greatly complicated by the need to consider physical and hydrological systems over time. With this as the general background, a research project based on Bayesian/Delphi analysis of expert opinions, was outlined to estimate probabilities of slope failures under any specific set of site conditions.

THE MODEL

Initially a few key on-site variables affecting mass failures were selected. This variable set was simplified, as illustrated in Table 1, to include four factors associated with natural landscapes; degree of slope, slope form, bedding plane angle, and soil type. Land management factors were limited to road standards, road age, timber age, logging method, and silvicultural method. Four categories of mass failure were defined; debris avalanche/flows and slump/earthflows (non-road related failures), road damage failures and off-road failures (which are road related by definition).

The second step was to obtain the relative probability of each failure type across each variable state. These probabilities were generated through intensive surveys of 35 soils, hydrology, and geology specialists. The respondents' experience with slope stability problems ranged from 4 to 35 years. Interview booklets were mailed to each expert prior to the interviews which were conducted primarily by phone.

These specialists were asked a series of questions that related a specific type of mass failure event to all variable states, one variable at a time. Only two variable state choices were included within each question in order to force the interviewed expert to focus only on the relative likelihood between the two choices posed. Using slope steepness and debris avalanche as an illustration:

Table 1--Variables Affecting Mass Failures Used Within the Inventory[1/]

Natural Landscape Factors	Road Related Factors	Harvest Related Factors
Slope percent Slope form Bedding plane angle Soil type	Road standards Road age	Timber age Logging method Silvicultural method

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[1/] Each variable type was subdivided into a few discreet variable states. For example, four slope percent classes were defined: 0-20, 21-50, 51-70 and 71+.

Assume:
a) You have $1,000 to wager for each question.

b) A debris avalanche/flow has just occurred on an acre of forest land.

Then, as a typical example, experts were asked to supply wager amounts to the following "paired" statements:

1. I wager $300 the acre of forest affected was on a slope of 51-70%, and I wager $700 it was on one greater than 71%.
2. I wager $10 the acre of forest affected was on a slope of 0-20%, and I wager $990 it was greater than 71%.
3. I wager $150 the acre of forest affected was on a slope of 21-50%, and I wager $850 it was one greater than 71%.

Each of these questions is related to the 71+% slope class. The relative probability for each slope class can then be computed based on the fact that given the condition that a debris avalanche/flow has occurred, the sum of the probabilities that an avalanche occurred associated with each class must equal one. simple arithmetic is then used to calculate the probability for each slope class. For this example response, when a debris avalanche occurs, the probability distribution that it will occur on either a 0-20%, 21-50%, 51-70% or 71±% slope class is respectively: .006, .110, .267 and .623. These are called conditional probabilities; that is, these are the probabilities of a debris avalanche having affected each slope class given the assumption that an avalanche has occurred.

Using the interview results, probability distributions were generated in the same manner for all other variables. Once the distributions for each variable were obtained, the probability for a combination of variables which collectively describe a particular site could be computed.

To this point, the technique generates "conditional" probability tables-tables of probability based on the assumption that an event has occurred. These conditional probabilities then must be adjusted to generate the actual probability that a mass failure will occur within a specified area. To accomplish this, the experts were asked, given an assumed hydrologic event of a given return interval, to estimate across all site conditions what the probability of either nothing or a slope failure event occurred. The product of the conditional probabilities multiplied by these event probabilities are called average event probabilities for a specific hydrologic condition.

The interview process provided data necessary to define the rate of mass failure occurrence by type, following harvest, and through the life of a timber rotation, and likewise following road construction. These data allow calculation of the rate of mass failure per acre or per road mile for specific periods of time and for each site by management regime. As an example, the natural hazard of failure was calculated for a 1,000 acre undeveloped site with shallow non-cohesive soils on normal slopes of 50-70% and where the bedrock dips steeply with the slope. This natural hazard can then be compared to the hazard following construction of 10 miles of unsurfaced secondary roads and following clearcutting by highlead. From start to finish, the calculations require nine steps, which are not reviewed in this discussion. The results are what are of interest, and they are shown in Table 2.

Summarizing the 1,000 acre example for this site, prior to management, an average annual rate of 0.023 slumps per year and 0.078 debris avalanches per year are expected. Clearcutting added an average of 0.07 slumps and 0.44 debris avalanches per year. Construction of 10 miles of forest road added an average hazard of 0.76 road mass failures and 0.58 road damage mass failures.

A major concern is: how reliable are these subjectively derived mass failure/storm event conditional probabilities. In order to gain some insight on this question, the subjectively derived probabilities for the complete survey were compared with the composite results of 9 widely separated studies reported within recent literature. The frequencies reported within the literature were examined on a per year, per acre basis for debris avalanches and slump earthflows as well as for off-road and road damage failures. Table 3 compares the rates of mass failure

Table 2--Example of Results Produced through the Mass Failure Hazard Index Prediction System

NATURAL CONDITION

Event	Natural Site Conditional Probability	Average Annual Event Probability	Expected # of Events/1000 Acres-Year
Nothing	.640	0.99966	999.901
Debris Avalanche	.262	0.00019	0.078
Slump Earthflow	.098	0.00015	0.023
	E = 1.0	E = 1.0	E = 1.0

CONDITION FOLLOWING HARVEST

Event	Conditional Probability Following Harvest	Average Annual Event Probability	Expected # of Events/1000 Acres-Year
Nothing	.2312	.99966	999.39
Debris Avalanche	.6341	.00019	0.52
Slump Earthflow	.1347	0.00015	0.09
	E = 1.0	E = 1.0	E = 1.0

CONDITION FOLLOWING ROAD CONSTRUCTION

Event	Conditional Probability Following Road Construction	Average Annual Event Probability	# of Events Per Year Per 10 Miles of Road
Nothing	.1451	.9502	8.66
Off Road Failure	.4536	.0267	0.76
Road Damage Failure	.4013	.0231	0.58
	E = 1.0	E = 1.0	E = 1.0

Table 3--Comparison of Survey Results to Nine Reports Within the Literature[1]

		Event Frequencies Per Acre Per Year	
	Event	From Survey	From Literature
Slope Events	Debris Avalanche	1.89×10^{-4}	0.57×10^{-4}
	Slump - Earthflow	1.51×10^{-4}	0.35×10^{-4}
Road Events	Off-Road	2.67×10^{-2}	1.98×10^{-2}
	Road Damage	2.31×10^{-2}	4.45×10^{-2}
	Total Road	4.98×10^{-2}	6.43×10^{-2}

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[1] Bishop and Stevens, 1964. Dryness, 1967; Rice, Corbett and Bailey, 1969; O'Loughlin, 1971; Coleman, 1973; Fiksdal, 1974a, b; Morrison, 1975; Swanson and Dryness, 1975.

derived from the literature to the rates of failure predicted by the survey results using the Mass Failure Hazard Index Prediction System.

The technique is flexible. Hazards for different sites at any stage of management can be compared. Incremental hazards of various management options, such as type and degree of roading and harvesting, can be compared on a site-specific basis over time; and probabilities of mass failure can be computed by period of time following road construction and harvesting. Of most importance, the variable sets are not closed; variables can be discarded or added.

As an alternative, tables generated by survey can be replaced with actual data gathered for a given geographic area-like the Idaho Batholith, the Oregon Coast, the California redwood region, or anywhere else. The technique provides a statistically valid means of correlating mass failures with landtype inventories.

LIMITATIONS WITH RELIANCE ON EXPERT OPINION

The modeling process is theoretically sound. the mathematics reduce to simple arithmetic. There is no searching for data in the literature that might fit a hypothesis, no fitting of curves to data or mathematical interpretation of processes. Essentially, the process should yield results which are as good as the judgement of the experts interviewed. However, by interviewing, analyzing the results, and reinterviewing, certain problems with modeling and expert opinion emerged. Some of these problems appear to apply to reliance on expert opinion in general.

One problem was that it is very difficult for most of us to think in several dimensions simultaneously. The interviewed experts were asked to think in terms of mathematical probabilities, to think about physical landscapes, to consider the effect of hydrologic events of large magnitude but rare occurrence, to think about large areas and long lengths of time. That is indeed difficult, and precisely the problem confronting all of us when asked to assess the risk, or results, of a management action.

A second problem was that nearly all the interviewed experts initially overestimated probabilities of failure. Estimates were not uncommon that were two, three, or even four magnitudes of order greater than the highest rates reported within the literature. There may be several reasons for this type of initial response.

First, experts in slope stability tend to spend a lot of time visiting, studying, and thinking about specific sites which have failed. What is not thought so much about are all the areas, miles of road, and years, where and when failures have not occurred. This phenomena may be something that is inherent in human nature. How many times have you spent half the day driving to the site of a mass failure and spent the rest of the day driving back-driving back over all the sites which did not fail?

Second, thinking in terms of very small probabilities is quite difficult. Consequently, great care needed to be used on "how" questions were asked. When the first interview was conducted in 1975, "wagers" were limited to $1,000. Even when an interviewed expert felt that there was a very low probability of failure for a given described situation, for instance on an acre of ground in a year's time, he was likely to wager two or three dollars. But even that is a probability of 0.02 or 0.03. Applied to a thousand similar acres, this translates to 20 to 30 failures. Applied to 100 years, it is 2,000 to 3,000 failures.

Part of this problem was solved by changing the wager to $100,000 when interviewing in 1980. But even so, the problem persisted. Great difficulty existed in visualizing how estimated probabilities of failure, which seemed very small, translated into very high rates of failure when applied to large areas over long periods of time.

This continuing problem was dealt with by trying to ensure during the early stages of an interview that the interviewed experts recognized what their probability estimates meant when extrapolated. As as example, an interviewed expert's estimate would be replied to by saying "your estimate of probability would translate into 1,200 failures per 1,000 acres in 10 years. Given that, would you like to change your bet?" In many cases they did. And then the interviews slowed way down as the experts began to conceptualize the probabilistic relationships through time and space: that is, to think in several dimensions simultaneously.

Even then, and sometimes even after revising initial estimates downwards by orders of magnitude, several interviewed experts phoned back hours or days later, asking to redo the interview. This was most common with those who had conducted an actual mass failure inventory and had compared their survey results with their field data. Without exception, the revisions were for lower estimates of risk.

That type of re-evaluation and revision was one of the most fascinating aspects of the modeling process: some of the experts learned something about their approach to qualitatively assessing slope hazard conditions and changed it.

CONCLUSIONS

While experts, like many of us, face real limitations in adapting perceptions on a given problem, in this study, many-probably most-did. The more deeply you are involved in a problem, adapting to new concepts will often be more difficult. However, in this case the experts with the broadest geographic experience, and experts who had conducted inventories, most often changed their thinking. Yet this evolutionary process ultimately required restructuring the general approach and five years of time. A key observation is that expert opinions on slope stability, while well-founded in experience and knowledge, may be unintentionally biased due to the problem of conentrating on sites which have failed, while not paying enough attention to those which did not. To managers seeking the advise of experts, as they should, you are urged to question expert opinions. But be cautious of bogging down in details. Step back and make sure you are satisfied that the opinion makes good sense in the broad context of your experience. Keep in mind that if an expert tends to overestimate risk of failure in a structured research interview, he is likely to also do so when evaluating the risk of management action at a specific site on the ground. For all of us who are experts, sound advice is to constantly remind ourselves to keep open minds. Assuredly, as our base of experience changes, our everyday concepts of problems and solutions will also change: sometimes dramatically.

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SUBJECTIVE TECHNIQUES FOR IDENTIFICATION AND HAZARD ASSESSMENT OF UNSTABLE TERRAIN

Dale Wilson

ABSTRACT: The key to any subjective mapping system designed to interpret slope stability is that the mapping system must be capable of extrapolating limited research data to a variety of landscapes based on observable characteristics of those landscapes. One of the most readily available and easily implemented methods is the historic approach using dominant geomorphic erosion processes.

The mapping system should be designed with definite interpretation objectives. If mapping units are to be used in land management planning, an interdisciplinary effort will be necessary for mapping unit design. Mapping units should be designed to enable data to be correlated with physical characteristics of the mapping unit. A mapping system based on dominant geomorphic erosion processes will allow mappers to stratify the base erosion rate over the landscape. Research and local data is then used to define relative risk of accelerated erosion resulting from various management practices.

Slope stability data used in water resource interpretations requires that the slopes' efficiency in delivering eroded material into live streams as sediment be considered in mapping unit design. This enables specialists to systematically predict the effect of management alternatives on water resources over time.

INTRODUCTION

This paper presents an approach to slope stability analysis that the Clearwater National Forest in northern Idaho has used to progress from specialist opinion to a documented decision-making tool. The result is a model which can be used to compare the stabilities of different watersheds and predict their response to various management alternatives. Variations of this type of approach are used widely by USDA Forest Service land managers in the western United States.

During the late 1960's roads were built in large areas of the Clearwater National Forest to gain access to diseased and dying timber. Much of the timber was harvested on steep, unstable slopes and many stability problems were encountered. Road-related landslides were the main stability concern as they interrupted road use and were expensive to repair. They also caused widespread and severe water resource damage. During this same period the Forest Service initiated intensive land management planning on all its lands. A major objective of the planning process was to assess slope stability and resultant environmental consequences of forest management practices.

A classification scheme was needed that divided a

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heterogenous landscape into units which responded similarly to various management practices with regard to engineering, watershed, and silviculture. Interdisciplinary requirements of the classification scheme resulted in an inventory that uses landform, geologic parent material, soils, and vegetative habitat types as mapping unit criteria.

Slope stability evaluation for mapping units uses the analysis of the dominant geomorphic erosion processes that control or have controlled the formation of landforms in the area. The intensity of the erosion processes is stratified using landform and parent material characteristics. The end product is a geomorphic process or erosion model for a large landscape such as a national forest. Mapping units are placed into categories that reflect the relative erosion rates. This enables the base erosion rate to be distributed over the landscape. The relative risk of resource damage is determined by assessing how different management practices will accelerate the base erosion rate. The stronger the historic evidence of recent slope instability, the greater the risk of management activities accelerating the instability.

This method is mostly subjective and is based on local observation and experience. An important factor is the ability of the mapper to extrapolate research findings from outside the area and adapt them to meet local conditions. The accuracy of this method depends on the experience of the mapper and that person's ability to make subjective observations and associations.

THE CLEARWATER APPROACH

In the Clearwater National Forest, landslides can be placed into two major classes: (1) rotational mass wasting (slumps, earthflows), and (2) debris avalanches and flows. Landform and parent material characteristics used to rate rotational mass stability are:

1. Incidence of subsurface water concentration (this is a prerequisite and must be present to evaluate other characteristics). Concave stream headlands and long, steep, dissected slopes are most likely to have subsurface water concentrations.

2. Depth of mantle. Deep mantles can concentrate larger quantities of ground water increasing the potential for deep-seated rotational failures.

3. Soil mantle characteristics. Soil texture classifications are used because of their correlation with soil shear strength. Silty-clay loam textures have the least shear strength and coarse, sandy textures have the greatest shear strength.

4. Parent material type and degree of weathering. Strongly weathered materials are subject to more mantle instability than weakly weathered materials; this is especially true if the material contains large amounts of mica.

Debris avalanches and flows occur in very different types of terrain. They consist of rapid releases of accumulated debris in steep draws and concave headlands. Slope characteristics used to rate these processes are:

1. Slope gradient. For this gravity-related process, the steeper the slope the more likely the process is to occur.

2. Potential of the slope to undergo dry surface creep. Creep provides a source of accumulation or buildup of unstable material. Loose, coarse-textured soils are most susceptible.

3. Visual evidence of past debris avalanches. This is reflected in scarred dissections on the slope and fans and cones along the lower margins of the slope.

The preceeding factors are evaluated and a relative rating of mass instability is given to each mapping unit. Risk of failure is presented to the manager only as relative hazard classes. True or acceptable risks are not defined. The manager must depend on specialists for recommendations in determining whether or not the risk is acceptable in order to achieve specific management goals.

DOCUMENTATION

A method readily available to a manager for documenting (or at least better defining) landslide hazard potential is to monitor actual landslides. More than 700 landslides of 10 cubic yards or more, which occurred on system roads in the Clearwater National Forest, were inventoried in 1974, 1975, and 1976. The project was done in cooperation with the Intermountain Forest and Range Experiment Station. Data was taken by a team of engineering, geology, and soils graduate students. Inventory data taken included type and size of failure; management history of the slope; road design, size, and type; and various mantle and landform characteristics. The data were analyzed (Megahan and others 1978) to determine the relationships between landslides and mapping unit properties. The relationship between mapping unit properties and landslide potential is displayed in tables 1 and 2. (Wilson and others 1983).

These data enable a further definition of relative potential for landslide occurrence but do not express numerical probability of failure for the hazard class. For example, the Clearwater landslide data showed that between 60 and 80 percent of landslides that occurred between 1974 and 1976 were on mapping units containing less than 10 percent of the total road mileage. Other mapping units accounted for less than 5 percent of the landslides but contained 40 percent of the road mileage.

Table 1.--Landtype properties used to rate slump-earthflow (rotational failure) mass wasting potential

Hazard rating	Low		Moderate				High				Very High	
Slope gradient	40%	40-60+%	<40%		40-60%	60+%	40-60%		60+%		60+%	
Dissection	yes dry	no	yes wet	yes	yes	yes/no	yes wet	yes	no	yes	yes	yes wet
Soil texture[1]	var.	SL & LS	var.	var.	SL & LS	var.	var.	SL & heavier	var.	SL & LS	SL & heavier	var.
Regolith depth	var.	>60 inches	>60 inches	>60 inches	>60 inches	>60 inches	>60 inches	>60 inches	>60 inches	>60 inches	>60 inches	>60 inches
Presence of mica	var.	no	var.	yes	no	no	var.	yes	var.	no	yes	var.

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[1] SL = silty loam; LS = loamy silt

Table 2--Landtype properties used to rate debris avalanche (planar failure) potential

Hazard rating	Low		Moderate		High	
Slope gradient	< 40%	40-60%	40-60%	60% +	60% +	60% +
Slope shape	Variable	Convex	Convex and Straight	Concave and Straight	Concave	Straight
Soil[1] texture	Variable	CL & SIL	SL & LS	SIL & L	SL & LS	SL & LS
Occurrence of old slide scars	Rare	Rare	Common	Common	Frequent	Frequent

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[1] CL = clay; SIL = silt; SL = silty loam; LS = loamy silt; L = loam

I consider this type of project to be one of the most beneficial ways to obtain data for evaluating the potential for landslide occurrence in an area where little or no local slope stability information is available to the specialist or manager. The cost of inventorying landslides on an area such as a national forest would be between $8,000 and $12,000 per year.

EVALUATION

Results of the Clearwater landslide study were immediately used in transportation planning and in road location, design, and construction. Landslide preventative measures sometimes included avoidance of road construction on mapping units that had the highest potential for landslide occurrence; and in the use of nonstandard construction methods such as full benching and end hauling of excavated material for use on roads constructed in more stable areas. Prior to 1975, the Forest was averaging over 200 road-related landslides per year. So far there have been less than ten road-related landslides per year on roads located, designed, and constructed since 1975.

Another method for evaluating the potential for landslide occurrence is through the use of the infinite slope equation in conjunction with characteristics of various mapping units. This again enables the specialist and manager to establish the relative stability of various mapping units by establishing a relative stability index. It must be kept in mind, however, that most landslides are associated with relatively small inclusions in larger mapping units. It is therefore a requirement that the frequency of occurrence of these inclusions be a mapping unit characteristic.

The major limitation of the above methods is that they provide a rating based on an average

Table 3--Nature and amount of disturbance by landtypes for alternative timber harvest access routes

Option	Road length	Road subgrade width	Side slope	Calculated area disturbed by road or cutting unit area	Landtype	Type of road prism
	Miles	Feet	Percent	Acres		
1	1.0	15	25	2.4	22-G03	Balanced
	1.0	15	25	2.4	22-G03	Balanced
	0.5	15	70	1.4	61-G08	Full bench
	1.0	15	50	4.1	60-G11	Balanced
				100	22-G03	
				125	23-G03	
2	1.5	15	25	3.7	22-G03	Balanced
	1.0	15	25	2.4	22-G03	Balanced
	1.0	15	40	3.2	32-G02	Balanced
				100	22-G03	
				125	22-G03	

relative potential for landslide occurrence for the entire area. This can be used only at the planning level. Onsite geotechnical investigation is required to determine the probability of a slope being unstable at a given site.

Analysis of slope stability as a factor in water resource management involves the additional estimation of the delivery potential of the eroded material to a live stream. A systematic analysis of sediment produced in a watershed serves as a method for estimating the role of slope stability in creating a potential for watershed damage. Wilson and others (1982) developed such a model for estimating eroded material delivered to live streams as sediment. The historic erosion approach is used to determine the natural erosion rates of mapping units. Erosion rates of all the mapping units within a watershed are then weighted according to the percentage of the watershed that they occupy. This enables the specialist to compare the relative erosion hazard from landslides for various mapping units and management practices. An example of the results of this kind of analysis are shown in table 3.

Coefficients can also be developed for the acceleration of sediment production for various management practices on each mapping unit. Data used to develop the coefficients should come from research conducted in areas that most closely represent the area analzed. Sediment data from research watersheds may meet most of the needs. In the case of the Clearwater National Forest, most of the data came from work in the Idaho Batholith (Megahan and Kid 1972a, 1972b; Megahan 1975, 1978). Results will enable the specialist to estimate the total sediment expected over time; for example, from construction of a mile of road in various mapping units. Sediment derived from all processes, not just landslides, should be represented.

Continued monitoring of sediment production in local watersheds subjected to a variety of management practices will improve the accuracy of predicting the response to local conditions. Local data also enables the specialist to predict the amounts of sediment that watersheds with various degrees of stability can tolerate without sustaining channel deterioration. This can be accomplished by monitoring sediment in several watersheds having a wide range of stability indices and management activities.

Using 28 watersheds with 4 to 10 years of monitoring data on drainages that have experienced various levels of development, the Clearwater National Forest methodology has shown the error in long-term sediment production estimates. These errors are on the order of plus or minus 15 percent in 64 percent of the watersheds. Three additional watersheds have errors of 100 percent or more and were not included in the statistics. Two of the watersheds are dominated by ancient landslide mapping units. Ancient landslides are extremely variable and unpredictable without onsite survey data.

Example of Model Application

The following hypothetical, simplified example of the application of these subjective analysis porcedures has been developed using a representative watershed situation and landtypes found in the Clearwater National Forest. A 1,000 acre watershed is defined that was formed on an old erosion surface by incision of a major drainage system (fig. 1). Elevations range from 4,000 to 4,900 ft. The bedrock underlying the watershed is granitic. Five different landtypes are identified.

Two options are considered in this example; each require 3.5 miles of road construction in 1982

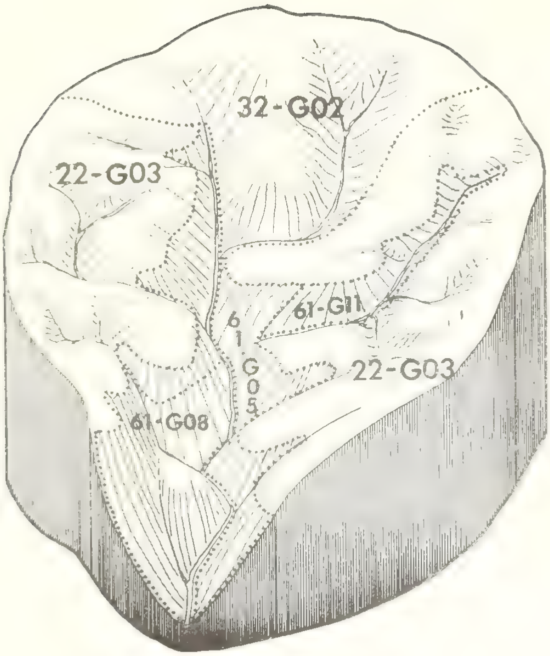

Figure 1.--Mapping units (landtypes) for a hypothetical 1000 acre watershed.

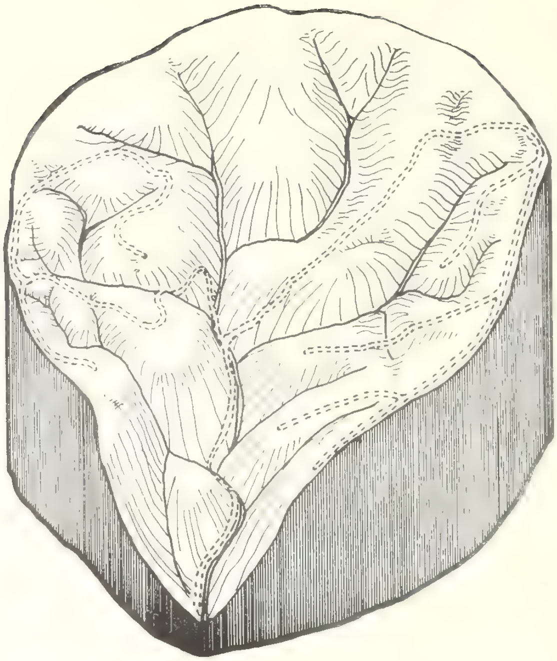

Figure 2.--Road and cutting unit locations for option 1 on the hypothetical watershed.

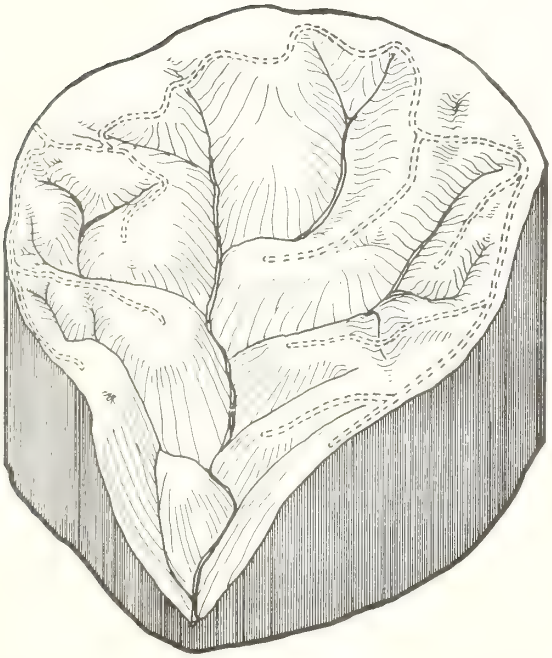

Figure 3.--Road and cutting unit locations for option 2 on the hypothetical watershed.

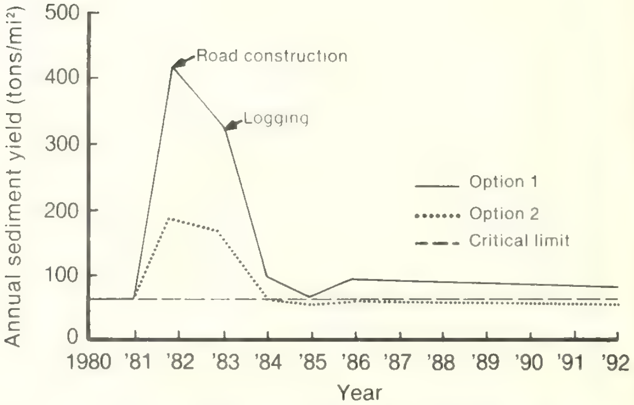

Figure 4.--Percentage change in sediment yields for alternative road and logging practices.

and the logging of 225 acres of timber by using clearcutting and tractor skidding in 1983. Option 1 (fig. 2) accesses the area from bottom of the watershed and crosses steep, high erosion hazard breaklands. Option 2 (fig. 3) provides access from the top of the watershed and crosses a lower erosion hazard terrain. The amount and type of disturbances by landtypes are given in table 3.

The data in the example were analyzed for a 10-year period following disturbance (fig. 4). The time dependence of the sediment responses was apparent. Sediment yields increased in 1981 in response to road construction. Rates decreased in 1982; but at a lesser rate than 1983 because of the 1982 logging activities. Additional decreases in sediment yield occurred over time but recovery to predisturbance levels was slow because of long-term erosion of roadcuts.

Figure 4 shows the percentage increase of sediment over undisturbed levels for the two management alternatives. The critical limit line represents the amount of measured sediment in other watersheds with similar natural stabilities that caused net channel changes and sediment deposition over a period of 5 years. Option 2 is clearly preferred over option 1 in terms of total increase in sediment production over time. Other considerations may be important, however: the nature of the beneficial uses of the water, the value of the water resource, the juxtaposition of development within this watershed over time and space with development of other watersheds in the area, and natural variability.

APPLICATION

This model has been used as a management tool for resource planning since 1976 with satisfactory results. The model has been continually revised and updated as local sediment monitoring data becomes available. It is used only as a tool, though, not as decision criteria; and it is always used with other information and professional judgment.

The model offers the manager three major advantages: it ties slope stability to sediment and water resource values; it analyzes the watershed as a system; and it analyzes the cumulated effects of past management in relation to potential effects of future management. The model is now being used in conjunction with a fisheries biomass model to predict the effect of management activities on fisheries productivity.

Without local quantitative data this procedure is empirical and as such has limited application elsewhere; however, the principals and procedures involved can be extrapolated anywhere. An analysis procedure of this type can be designed for use in areas with minimal local erosion and sedimentation information using the basic principals described to define relative erosion hazard ratings. The evaluation may then be used to design erosion and sediment monitoring programs that serve to document and increase the accuracy of prediction procedures. This enables the extrapolation of the data to other watersheds with similar natural and management-induced erosion rates. Basic mapping unit requirements for implementing a systematic watershed sediment analysis are:

1. The dominant landforming and erosional processes of an area must be recognized.

2. The relative role of processes must be understood.

3. Mapping units must be designed to rate the dominant erosion processes.

4. Mapping units must be designed using criteria essential for making interpretations of sediment delivery efficiency from slopes.

5. The watershed system must be limited in sediment supply in the natural state.

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THE ENGINEERING APPROACH TO LANDSLIDE RISK ANALYSIS

W. L. Schroeder

ABSTRACT: Approaches to evaluation of landslide risk may be grouped in two broad categories. Inductive evaluation of risk is based largely on experience and generally arises from a process of logical reasoning, based on observations. In the case of landslides, physical conditions where there is a concern for sliding are compared to those where landslides are known to have occurred, and appropriate conclusions are drawn. Deductive approaches begin with the acquisition of certain quantifiable information and result in predictions, based on that information and analytical models, of a certain outcome. In this sense, deductive approaches to landslide risk evaluation are largely analytical or theoretical. The true engineering approach includes elements of both of these processes. Landslide risk analysis is a perfect example of the need to employ both inductive "judgment" and deductive "analysis" for effective decision making. Probability concepts are used in the paper to make this point.

INTRODUCTION

Geologists and civil engineers spring from diverse educational backgrounds. Over the past 50 years, the related professions of engineering geology and geotechnical engineering have emerged (figure 1). The geologist primarily uses inductive reasoning and observes processes such as landslides and the related physical features and draws conclusions concerning the likelihood that these processes may occur in similar settings in the future. Such conclusions are qualitative and expressed descriptively. The civil engineer operates using deductive logic and analyzes the landslide process to obtain numerical answers and to draw quantitative conclusions. The apparent precision of this numerical answer lends it believability and, in some quarters, infallibility.

The engineering geologist and the geotechnical engineer occupy a gray area in which geological and engineering skills overlap. My perspective is that of geotechnical engineer, and my task is to explain the analytic approach to landslide risk analysis. There are shortcomings, however, in the analytical view of what is certainly a complex natural phenomenon. After presenting this approach, I will discuss these shortcomings and offer a true engineering approach that incorporates certain skills from the science of geology.

LANDSLIDE MECHANISMS AND MECHANICS

Varnes (1978) provides a classification for various types of earth movements. Every type can be analyzed quantitatively to predict if it may happen or, if it has happened, whether it will continue. Engineers focus their attention largely on earth movements classed as slides.

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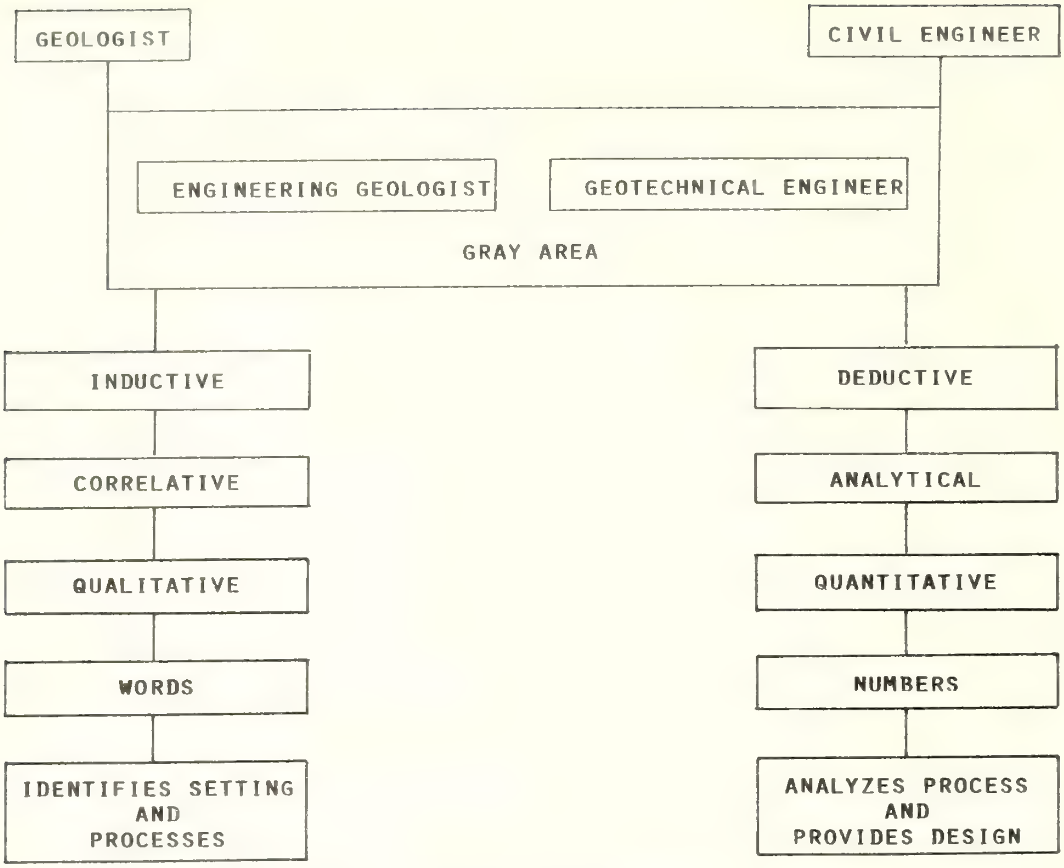

Figure 1.--Description of earth science and engineering professionals.

Mass movements in the forest setting nearly all begin with a rotational or translational slide.

Landslides start when stresses exceed soil strength. The factor of safety (ratio of strength to stresses) is a convenient way to express relative stability. If the factor of safety exceeds one, the slope is stable. A computed factor of safety that is less than one indicates that a slope should fail.

Landslides have length, width, and depth. Slopes are analyzed using the forces on a potentially failing mass. Usually, a section of the potentially failing mass with unit width and actual length and depth is considered. Figure 2 shows a section illustrating potential rotational (ab) and translational (ac) failure surfaces.

Geometric, geologic, and hydrologic factors govern the behavior of slopes. Topography determines the upper boundary of a sliding mass. A sliding surface determines the lower boundary. The sliding surface is known only if the slide has already occurred or an adequate drilling or instrumentation program has been implemented. The possibility of a landslide can be assessed by determining which of many possible sliding surfaces has the lowest factor of safety. If the possibility of sliding along a particular geologic discontinuity is to be evaluated, the critical failure surface may be defined in advance. Geologic factors that must be known include soil weight or density, and strength. Shearing strength, S, may be thought of as the unit resistance between soil layers sliding on one another. It is characterized by the Mohr-Coulomb equation,

$$S = c' + (p - \mu) \tan \phi' \qquad (1)$$

where c' is cohesion, p is normal stress, μ is the water pressure on the potential failure surface, and ϕ' is the angle of internal friction. Cohesion is the strength which exists without any normal pressure. The other component of strength arises from friction between soil grains. Without normal pressure, no frictional strength exists. The tangent of the angle of internal friction may be considered as a coefficient of friction. Hydrologic factors such as rainfall, snowmelt, infiltration, and permeability determine the effects of water on landslides. These factors determine the water pressure, μ, on the failure surface. Water also influences apparent cohesion that exists in moist soils. Of all the factors that influence landslides, the most difficult to determine is water pressure. Actual pore water pressures are hardly ever known.

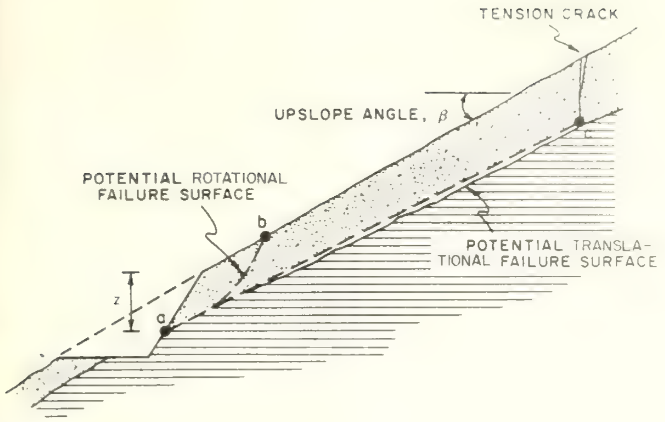
TENSION CRACK
UPSLOPE ANGLE, β
POTENTIAL ROTATIONAL FAILURE SURFACE
b
c
z
a
POTENTIAL TRANSLATIONAL FAILURE SURFACE

Figure 2.--Section through slope illustrating potential failure surfaces.

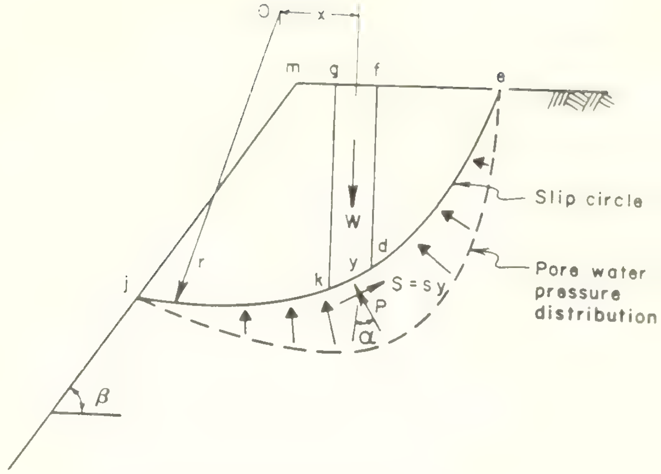

Figure 3.--Slide mechanism with rotational failure surface.

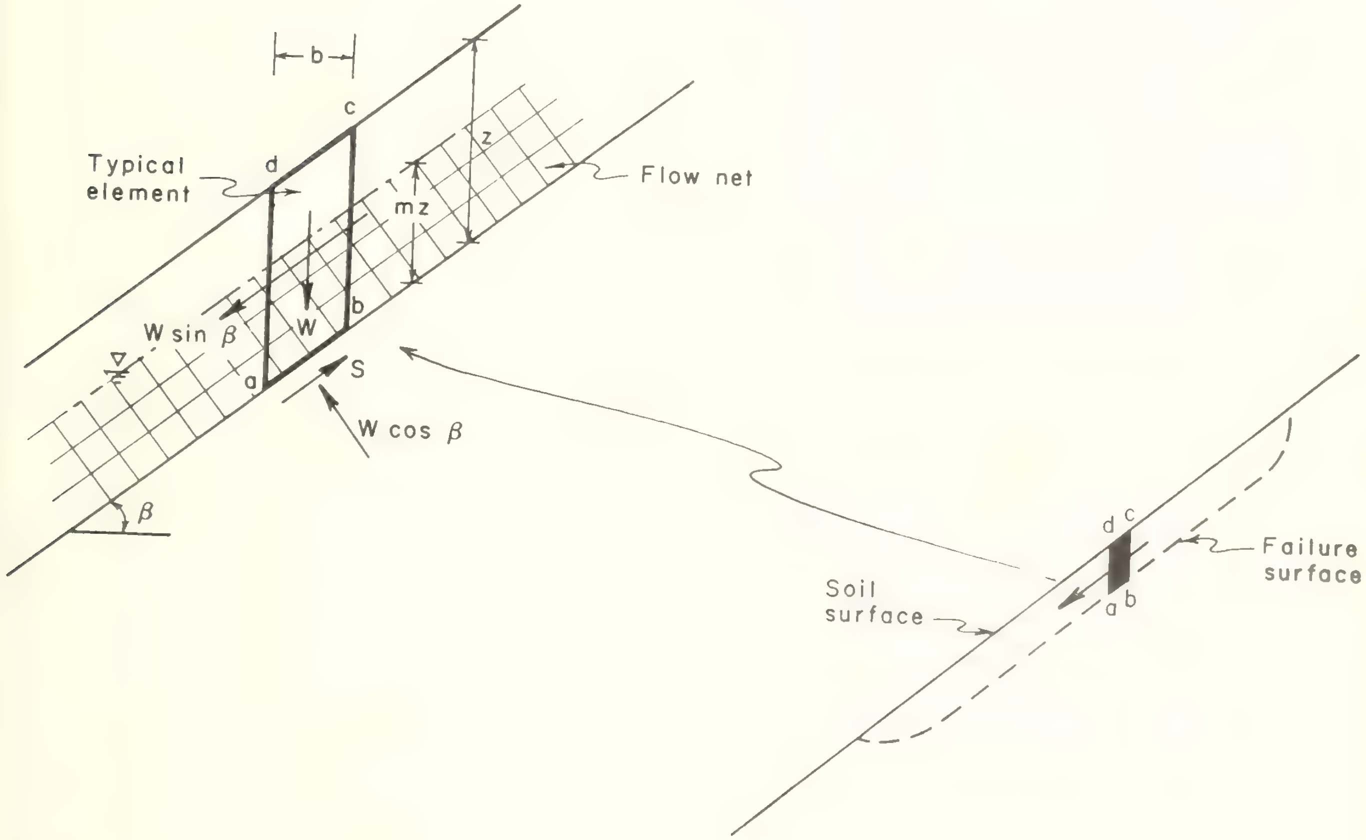

Figure 4.--Slide mechanism with translational failure surface.

Rotational Slides

Arc surfaces (see je, fig. 3) are characteristic of slides in cohesive soils. The mass, ejm, is considered to be of unit width. A typical slice of the potential sliding mass, dfgk, is illustrated. The sliding mass is divided into a number of such slices for analysis. the mass is considered to rotate about 0, at radius r. The forces on each slice include the slice weight, W, and the strength at its base, S. The weight, as determined by soil density and slice dimensions, creates a moment, Wx, about 0. The unit strength, S, is calculated from equation (1). The normal force, P, is determined by taking that component of weight perpendicular to kd. The sum of the moments tending to create the failure is designated $\sum Wx$, and those tending to resist failure as $\sum Sr$. The ratio of the resisting moments to the driving moments is the factor of safety, FS:

$$FS = \frac{r}{\sum Wx} \sum c'y' + (P - \mu y) \tan \phi' \qquad (2)$$

Translational Slides

Figure 4 shows a failure parallel to the topographic surface and the detail of forces on a typical slice from the sliding mass. Such slides are characteristic of cohesionless soils or of cohesive soils in which a weak soil plane exists. Because every slice, such as abcd, is considered to be the same, only those forces operating on one slice need to be considered. Such failures are referred to as infinite slope or long slope failures. Forces downslope are compared to those upslope to determine the factor of safety. The forces upslope are determined by computing the shearing strength (S) from equation (1) on the failure surface, ab. Downslope driving forces are calculated from the slice weight and slope angle. The factor of safety is:

$$FS = \frac{c'}{\gamma z \cos\beta \sin\beta} + \frac{1 - m\gamma_w}{\tan\beta} \frac{\tan \phi'}{\tan\beta}, \qquad (3)$$

in which β is the gradient of the failure surface, γ is the unit weight of soil, γ_w is the unit weight of water, and m is the ratio of water depth to soil depth, z.

SHORTCOMINGS OF LANDSLIDE ANALYSIS

Soil strength at lateral boundaries resists movement in a landslide. Because these forces are not accounted for in the usual two-dimensional analysis, the factor of safety is usually underestimated. Aside from this shortcoming, available methods of slope analysis are reliable. Cost and time limitations, however, usually limit our knowledge of input data. Therefore, in natural slopes where geologic conditions are nearly always complex, where ground water conditions are seldom reliably known, and where even the topography must be approximated for analysis, engineering analysis can never be considered to have great precision.

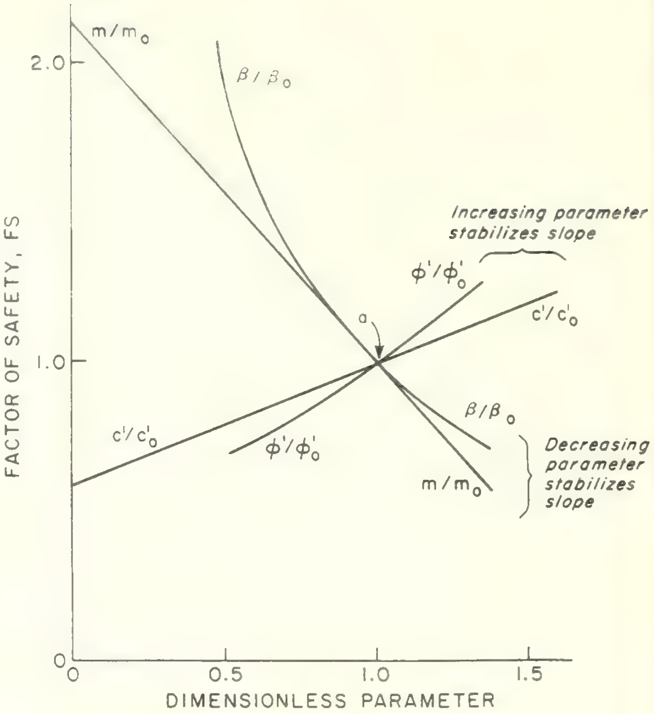

Figure 5.--Sensitivity diagram for longslope failure.

Consider a long slope with β (gradient of the failure surface) = 20°, z (vertical distance from ground surface to failure plane) = 2.4 m (7.9 ft), γ (unit weight of the slide material) = 1.5 Mg/m^3 (95.5 pcf), Ø' (angle of internal friction) = 32°, and c' (cohesion) = 5kN/m^2 (104.4 psf). Consider also that the ground water level is at the surface so that m = 1. From equation (3), the factor of safety of this hypothetical slope is one. We can now examine the influence of poorly defined input parameters by assigning different assumed values to the above quantities. The originally assumed values are assigned the subscript, o, and newly assumed parameters no subscript. Repeated calculations with equation (3) produce the sensitivity diagram shown in figure 5. From figure 5, an increase in Ø' or c' results in an increase in the factor of safety. Increasing the water level parameter, m, or the slope angle, β, results in a lower factor of safety. Point (a) represents the factor of safety of the slope if all input parameters are known accurately. Figure 5, then, shows the consequences of variable natural conditions or poor input in the analysis. For instance, if all input is perfect except for m, and it is assumed that $m_o = 1$ when for real conditions m = 0.5, the factor of safety of the hypothetical slope is not 1 but 1.6. The difference in water depths for these cases is only 1.2 m (4 ft), but this modest difference

Table 1--Soil Properties for Oregon and Washington Coastal Ranges (from Schroeder and Alto 1983)

Parameter	Value
Mean angle of internal friction, $\phi'_{ave.}$	35.4°
Standard deviation, angle of internal friction, $\sigma_{\phi'}$	4.6°
Cohesion, where present, c'	6.86 kN/m^2 (143.3 psf)
Mean saturated unit weight, $\gamma_{ave.}$	1.82 Mg/m^3 (116.06 pcf)

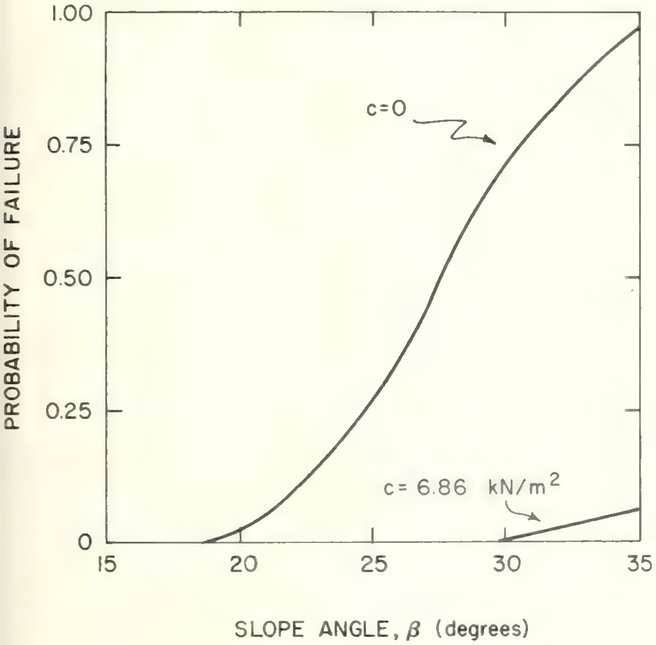

Figure 6.—Probability of failure for hypothetical slopes in the Coast Ranges in Oregon and Washington (see text for conditions).

significantly alters the computed safety factor. As a further example, consider the data of Yee (1975), who showed that the capillary tension of about 0.6 m (2 ft) of water, which exists in most Oregon Coast Range soils during periods of low rainfall, produces an apparent cohesion of about 4.6 kN/m^2 (95 psf), approximately equal to the cohesion used in constructing the sensitivity diagram. A rise in ground water level of 0.6 m (2 ft) would destroy this apparent cohesion. According to figure 5, the factor of safety of the slope would drop from 1 to about 0.6, and the slope should certainly fail. Illustrations like this show that erroneous input can have a dramatic influence on the outcome of analysis for stability. In practice, there are limits on our ability to obtain this input. Therefore, engineering analysis for slope stability seldom produces precise answers.

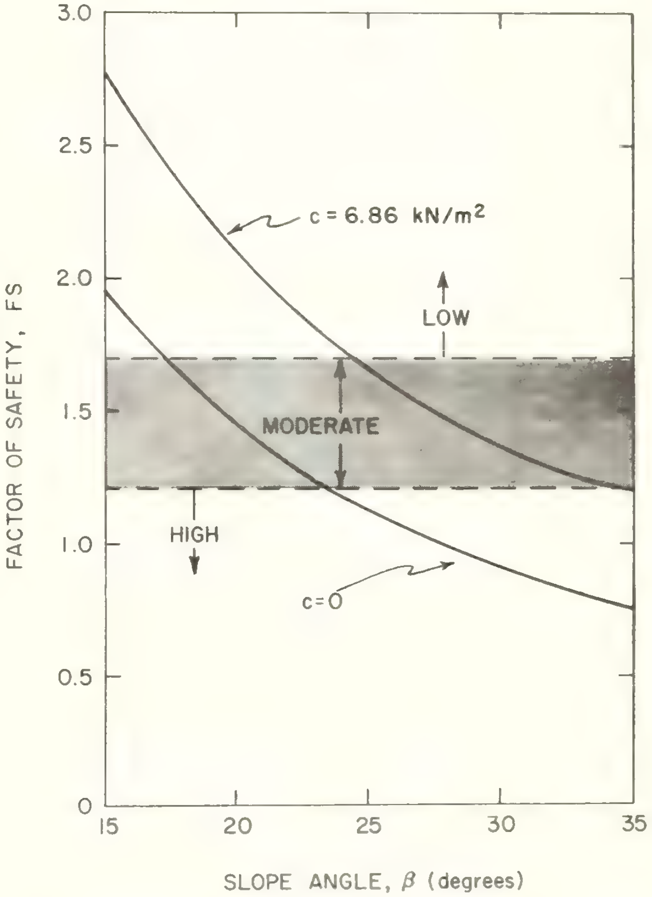

Figure 7.--Calculated factor of safety for hypothetical slopes in the Coast Ranges in Oregon and Washington (see text for conditions).

In evaluating the stability of slopes, an engineer must decide on an acceptable calculated factor of safety. This decision requires judgment. It is generally accepted that a reasonable factor of safety is 1.5, but, if little effort is to be expended to define input, the factor of safety should be higher.

Table 2--Summary of landslide risk assessment[1/]

Indicator	Slope			
	20°	25°	30°	35°
Calculated mean factor of safety	1.440	1.124	0.906	0.748
Probability of failure	0.024	0.260	0.729	0.976
Relative risk category	Low	Moderate	High	Very high
Observed slide activity	None	Dormant	Dormant	Active

[1/] Data on which factor of safety and probability calculations were based.
Mean soil properties: $\emptyset' = 35.4^\circ$, $c' = 0$, $\gamma = 1.82 \mathrm{Mg/m}^3$ (116.06 pcf).
Mean soil depth: $z = 1.83$ m (6.0 ft).
Mean water depth: $mz = 0.92$ m (3.0 ft); $m = 0.5$.

PROBABILISTIC APPROACHES

In nature, soil conditions are never uniform. Schroeder and Alto (1983) have shown, for instance, that the population of strength parameters for soils in the Oregon and Washington Coast Ranges is normally distributed, with properties shown in table 1. Recent approaches to engineering analysis of slopes can use such data to express the reliability of safety factor calculations.

From table 1 and equation (3), the factor of safety in a long slope with $z = 1.83$ m (6 ft), $m = 0.5$, and $c' = 6.86 \mathrm{kN/m}^2$ (143.3 psf) is:

$$FS = \frac{0.206}{\cos\beta \sin\beta} + 0.731 \frac{\tan \emptyset'}{\tan\beta} \qquad (4)$$

If we follow the approach of McGuffey, and others (1981) and consider the variability of the shear strength parameter, $\emptyset'$, noted in table 1, the expected value of the factor of safety (mean value) is:

$$E(FS) = \frac{0.206}{\cos\beta \sin\beta} + \frac{0.524}{\tan\beta} \qquad (5)$$

If $c' = 0$, the first term in equation (5) is lost. The standard deviation of the distribution of safety factor with or without cohesion, c', is

$$\sigma_{FS} = \frac{0.089}{\tan\beta} \qquad (6)$$

The probability of a slope failure is the probability that the factor of safety will be less than one. It can be computed for the mean and standard deviation from standard probability tables (Brownlee 1965) as:

$$P\{FS<1\} = P\{1\} = \Phi[u] = \Phi\left[\frac{FS-E(FS)}{\sigma_{FS}}\right] =$$

$$\Phi\left[\frac{1-E(FS)}{\sigma_{FS}}\right] \qquad (7)$$

Results of these computations are summarized in figure 6, which shows that the probability of failure for cohesive slopes as steep as 35° is quite low (that is, < 0.07). The mean value of $\emptyset' = 35.4^\circ$ would have given FS = 1.18 for a 35° slope. If there is no cohesion, the probability of failure is much larger. With probabilistic analysis, the engineer can judge the acceptability of a finite probability of failure instead of the adequacy of a calculated factor of safety.

Calculated factors of safety for our example problem for soils having $\emptyset' = 35.4^\circ$ are presented in figure 7. Often, engineers assume that "high" risk of failure corresponds to calculated factors of safety below 1.2 and that "low" risk corresponds to calculated factors of safety above 1.7. For the cohesive case, from figure 7 we see that a "high" risk occurs for $\beta > 34.5^\circ$ and a "low" risk exists for $\beta < 24.5^\circ$. The "high" risk, according to figure 6, corresponds to a probability of about 0.06 or 6 percent. The "low" risk is very small. But for the noncohesive case, the "high" risk ($\beta > 23.5^\circ$) probability is about 18 percent. Identical factors of safety may represent different risk levels.

The foregoing illustrates probabilistic analysis in which one parameter is variable. In reality, all parameters in equation (3) are variable. That variability may be quantified if adequate data are available, and a similar, but more complex, derivation of the risk of failure can be made. Wu and Swanston (1980) discuss this procedure. Although probabilistic methods allow engineers to quantify risk more clearly than does the factor of safety approach, they do not tell us what an acceptable risk level is. That decision must still be based on judgment.

TRUE ENGINEERING ANALYSIS

The process of assessing risk according to the true engineering approach is illustrated in figure 8. The proper use of this process requires considerable time and resources. Judgmental decisions are made at every step, and the outcome of the analysis depends on these judgments.

Suppose that the risk of landslides in a watershed in the central Oregon Coast Range have to be evaluated. Topographic maps are available, and a geologic reconnaissance has been completed. Areas with active and dormant landslides have been identified, and the mean soil depth over the watershed has been determined to be 1.83 m (6.0 ft). Stability when seepage is at mid-depth in the soil profile is to be considered. Soil conditions determined by Schroeder and Alto (1983) are applicable, and the soils are cohesionless. Analyses for the factor of safety and probability of failure yield the results indicated in table 2.

We may also assign relative risk by drawing the inductive conclusion that landslides will occur again where they have happened before. In table 2, for instance, the areas of active landsliding are identified as very high risk areas. This criterion overrides those based on stability calculations. To use the results in table 2, an engineer would first refer to areas mapped by the geologist as having active or dormant landslides and judge, without recourse to analysis, that these areas would have more than a low probability of future failure. The inductive process could by itself lead to an assignment of relative risk. On the other hand, the hypothetical watershed may show no signs of past landslide activity. In that case, there is no basis for drawing conclusions concerning risk in different areas of the watershed except a deductive analysis. Risk level is then based on factor of safety and probabilistic determination. In the best of all situations, of course, adequate data are available for both the deductive and inductive processes to work.

SUMMARY

Either inductive or deductive approaches, or preferably both, can be used to assess landslide risk. Often the former is the geologist's exclusively, and the latter is the engineer's. Without judgment, the deductive approach, is, in reality, no more than analysis. True engineering involves judgment. Whether analysis be based on discrete landslide modeling or probability concepts, the current state of the art in engineering requires reliance on inductive reasoning and analysis tempered with judgment. This is particularly true when area-wide studies of landslide risk are required. It is, therefore, not appropriate to assign these duties to persons who are not familiar with the limitations of the analytical methods available to the engineer.

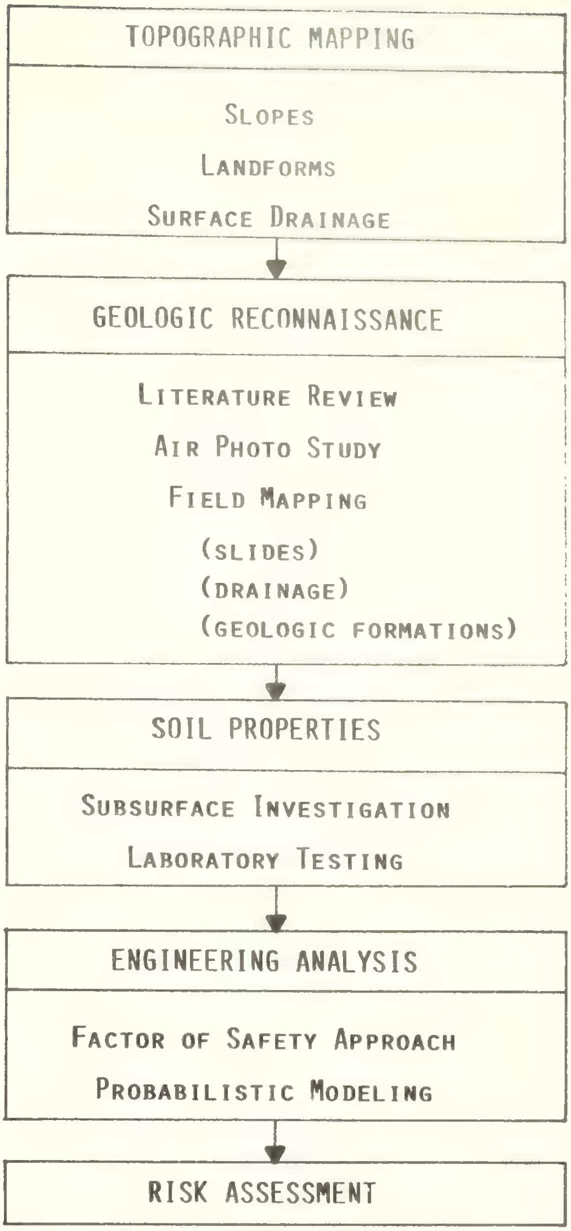

Figure 8.--Methodology for landslide risk assessment using the true engineering approach.

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COMPUTER-BASED
LANDSLIDE DELINEATION AND RISK ASSESSMENT PROCEDURES
FOR
MANAGEMENT PLANNING

Tim J. Ward

ABSTRACT: This paper explores what computer-based tools are available to the planner/manager. Concepts and principals are discussed, and an application of one method is described.

The primary emphasis is on the merging of theoretical concepts with computer-aided decisionmaking. The factor-of-safety approach for delineating hazardous slopes is used as the basis for many types of decisionmaking processes. Low factor-of-safety values are unsafe and therefore delinate hazardous areas. The factor of safety can also be used as an indicator of landslide risk or of the probability that a slope failure might occur given the uncertainty of the controlling variables. Forecasts of the direction this approach will take in the future are presented.

INTRODUCTION

Effective management of watersheds requires careful planning based on the best information available. The final management decision or recommendation must be made by the planner or planning team from technical input and experience. The mangement planning function is, therefore, a combination of technical expertise and information and the experience of the planners involved. This combination of qualities can be cast in quantitative terms so that it can be made transferable between individuals through the use of computer modeling.

The Modeling Game

Computer usage in management planning has become both a boon and a bane. One negative aspect is that sometimes the computer generated results form some "model" of the forest system and are used as the ends themselves. This is an incorrect approach to management planning. Instead, computer models (i.e., mathematical abstractions of real physical processes), should be viewed and used as a means to an end. Recently, a forest management project in New Mexico was discontinued because the computer results were erroneous and this was not detected soon enough to make necessary changes. It was only after the numbers (results) were compared with physical reality that someone discovered that the model had a higher harvest than there were trees!

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Although these observations are rather negative, do not construe them to be anticomputer-based modeling. In fact, use of the computer has greatly enhanced the management planning function in that a large number of potential scenarios can be analyzed in a relatively short time. The scenarios can provide a matrix of outcomes upon which further analyses can be conducted. One aspect of developing numerous scenario results is that one can start to believe that the watershed or landscape will respond as the model indicates. In truth, the results are how the model responds, hopefully as a relative representation of the true physical world. Just as with arcade games, it is easy for the unseasoned modeler to become enthralled by the "modeling games" and not recognize when the results and reality no longer coincide.

The power and pervasiveness of computer-aided decisionmaking in management planning requires that the managers/planners have an idea what models are available and if they truly meet the perceived needs. There are models for timber growth and harvesting, for animal population dynamics, for watershed rainfall-snowmelt-runoff-sediment yield prediction, and for landslide delineation and risk assessment (as this paper explores). Not only are there different types of models for different aspects of the planning function, but there are different levels of model sophistication. These range from computerized curve fitting through those detailing the basic physics of the important processes. Although more sophisticated, these last types provide the best answers relative to forest management planning. One of these models is presented here to acquaint the reader with modeling.

LANDSLIDE DELINEATION: A PHYSICALLY-BASED APPROACH

General Methodologies

The concept of landslide delineation, or more properly landslide potential delination, comes from the recognition that landslides occur (usually) when slopes are relatively steep, the ground is "weak," and water is present. There have been numerous approaches developed for delineation of potential landslide areas including on-ground monitoring, remote sensing techniques, factor overlay methods, statistical models, and geotechnical process models. Many of these approaches are discussed in Schuster and Krizek (1978).

The most common delineation method used is factor overlay of a combination of landslide producing elements. Krynine and Jud (1957) note that landslides occur in a regional framework such that certain factors common to a region contribute to land sliding. Baker and Chieruzzi (1959) expand this concept to develop a physiographic classification of landslide hazards based on topography, erosional development, and associated rock types. Blanc and Cleveland (1968) were among the first to attempt to delineate landslide areas by use of selected factors. Evans and Grey[1] present a methodology for mud slide risk delineation in southern Ventura County, California. Cleveland (1971) summarizes and presents factors importan in regional landslide prediction. The approach described by Nilsen and Brabb (1973) and the Committee on Methodologies for Predicting Mudflc Areas (1982) also follow a systematic methodolog using landslide factors. In this overlay approach, certain factors related to landslide occurrence are individually delineated. For example, if landslides occur where steep slopes, weak earth materials, and water are all coincident, then these factors should be used as slope stability indicators. Areas where factors coincide can then be classified as a high hazard potential (Simons and Ward 1976). Although not explicitly stated in delineation schemes, this idea is the basis for most techniques.

Another type of landslide hazard delineation methodology is based on geotechnical models. One such approach has been developed (Ward 1976; Ward and others 1980, 1982) and can be used as a framework for other approaches (e.g., Edil and Schultz 1983).

Framework for the Computer-Based Approach

Current delineation techniques utilizing geotechnical models are available for a wide range of conditions. A basic framework for all types of models should include:

1. The pertinent mathematical equations(s).

2. A method for converting topographic, vegetative, water, and soil-geologic information into a digitized form suitable for the mathematical equations(s).

3. An interactive feature that allows the manager/planner to engage in "what-if" games.

4. A meaningful output feature or display that is easily understood.

The approach of Ward (1976) and Ward and others (1982) is designed to meet these criteria. In the Ward approach or model, a simplified infinite slope factor-of-safety equation is used to determine the ratio between the resisting factors preventing landslides and the driving factors creating landslides. The equation was cast in probabilistic terms so that a mean factor of safety (FS) and a standard deviation (or a variance, VAR[FS]) could be computed. The basic equations were:

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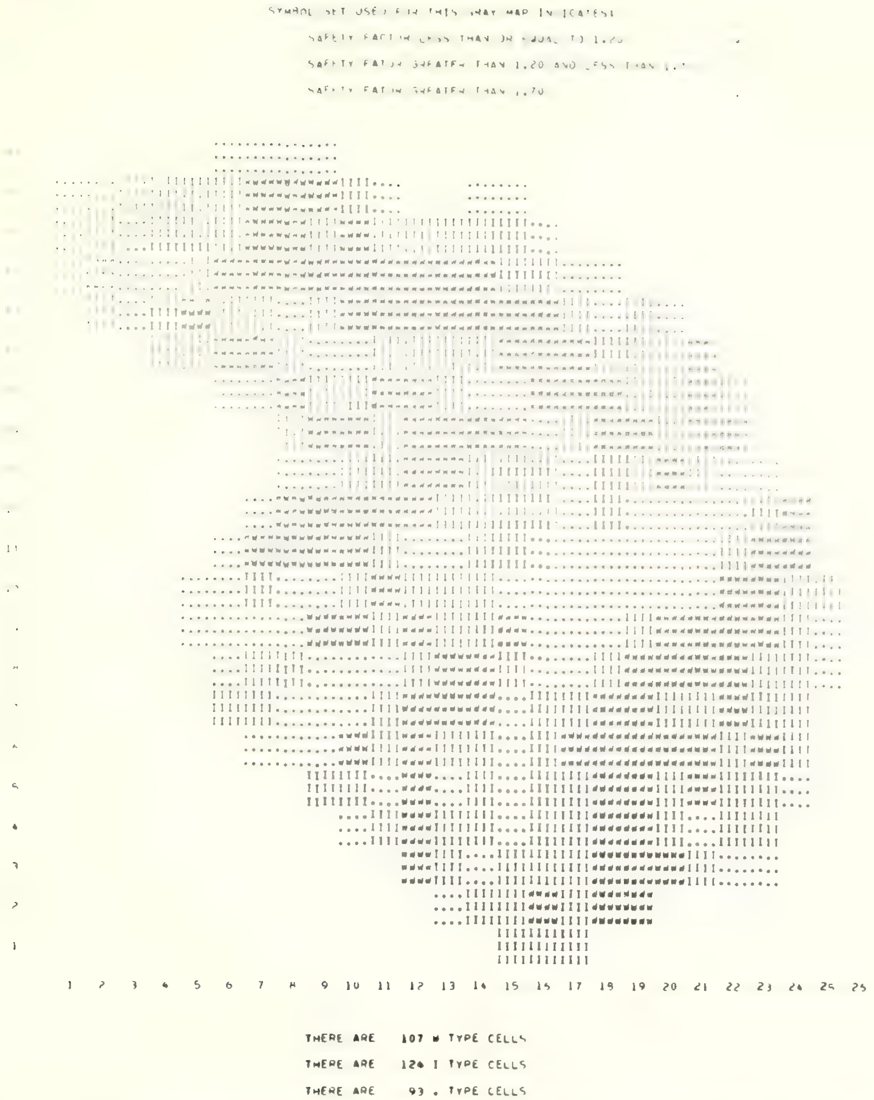
[1] J. R. Evans and C. H. Grey. Analysis of landslide risk in southern Ventura County, California. Unpublished report prepared for the U. S. Department of Housing and Urban Development. On File at the California Division of Mines and Geology, Sacramento, California.


SYMBOL SET USED FOR THIS GRAY MAP INDICATES
SAFETY FACTOR LESS THAN OR EQUAL TO 1.20
SAFETY FACTOR GREATER THAN 1.20 AND LESS THAN 1.70
SAFETY FACTOR GREATER THAN 1.70
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THERE ARE 107 W TYPE CELLS
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THERE ARE 93 . TYPE CELLS

Figure 1.—Gray area or print density map of Starfish Creek, Alaska, showing baseline factor-of-safety conditions (undisturbed).

$$FS = L1\ (c_s + c_r) + L2\ (\tan \phi) \qquad (1)$$

and

$$VAR(FS) = L1^2\ (c_s + c_r) + L2^2\ (\tan \phi); \qquad (2)$$

where

c_s = soil cohesion,
c_r = "cohesion" added by roots,
$\tan \phi$ = soil internal friction angle, and
L1, L2 = variables containing terms for soil weight and depth, water effects, vegetation, and slope inclination.

From these equations, the FS value could be ranked according to some hazard classification. The probability of a landslide occurrence was cast in terms of the variability of the c_s, c_r, and $\tan \phi$ values while the L1 and L2 were fixed. The probability of a landslide, then, is the chance that all the factors exist that would lead to a failure; whereas potential is the determination that factors exist that tend toward (or away from) failure. Edil and Schultz (1983) indicate that hazard zoning based on the probability determination contains more information than just the potential.

Data Needs

A strength of the approach just discussed is also a weakness--data. The geotechnical model requires an estimate of soil parameters, vegetation and topography. This information can be determined from tables presented by Ward

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SYMBOL SET USED FOR THIS GRAY MAP INDICATES:
     PROBABILITY OF SLIDING HIGHER THAN 90 PERCENT                                   W
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     PROBABILITY HIGHER THAN  30 PERCENT AND LESS THAN O EQUAL TO  60 PERCENT        I
     PROBABILITY HIGHER THAN 0 PERCENT AND LESS THAN OR EQUAL TO 30 PERCENT          =
     PROBABILITY OF SLIDING EQUAL TO 0 PERCENT                                       .
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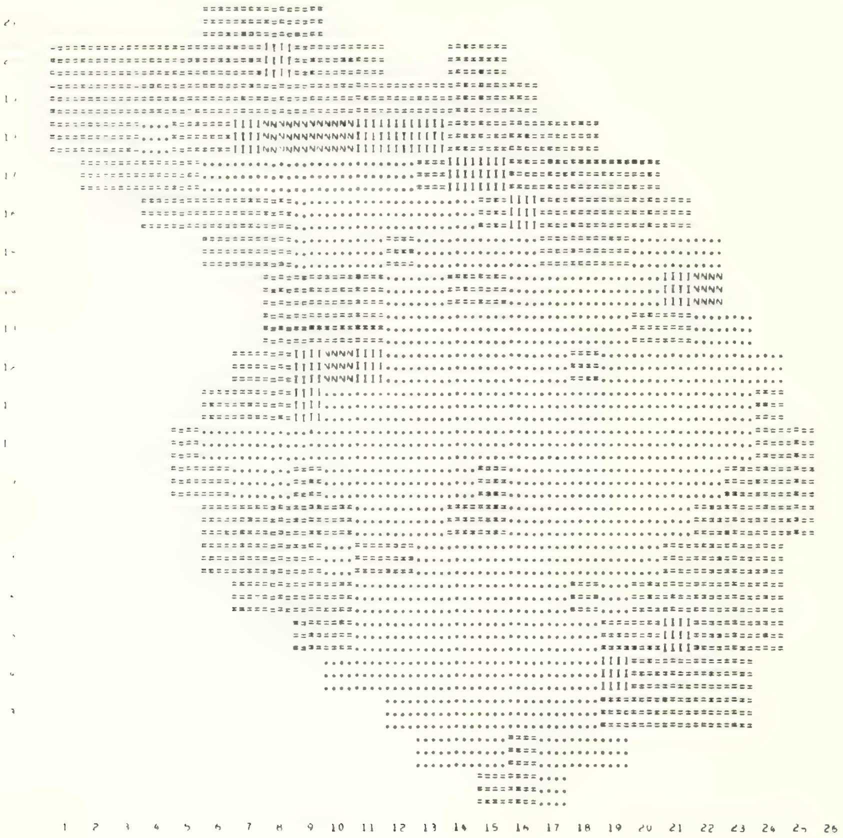

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Figure 2.—Gray area or print density map of Starfish Creek, Alaska, showing baseline probability of failure conditions (undisturbed).

(1976) or Campbell and Ward[2]. Data entry is tedious but is assisted by software packages that arrange the information into a usable form. In this approach the data (parameters, slope, etc) are assigned to a predetermined rectangular grid that is overlaid on the watershed of interest. This grid can vary in size, but larger grids mean more averaging of data and smaller grids mean more intense data requirements. In general, the approach is well suited for land management applications in that each grid cell can be assigned a potential or probability value.

The original approach was not designed with an interactive capability. Instead single data files (or if necessary, multiple data files) could be edited by the user and the model executed again. Interactive computing using a virtual machine concept has negated the need for a truly interactive program.

Display

The results of the geotechnical modeling approach should be displayed in a form that is easy to use. Tables of numbers are tables of numbers. For more impact, nothing ia better than a visual display. When the watershed or landscape is

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[2] Campbell, R. E.; Ward, T. J. The LSMAP methodology and uses guide for delineating potential landslides. unpublished manuscript. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 1982.

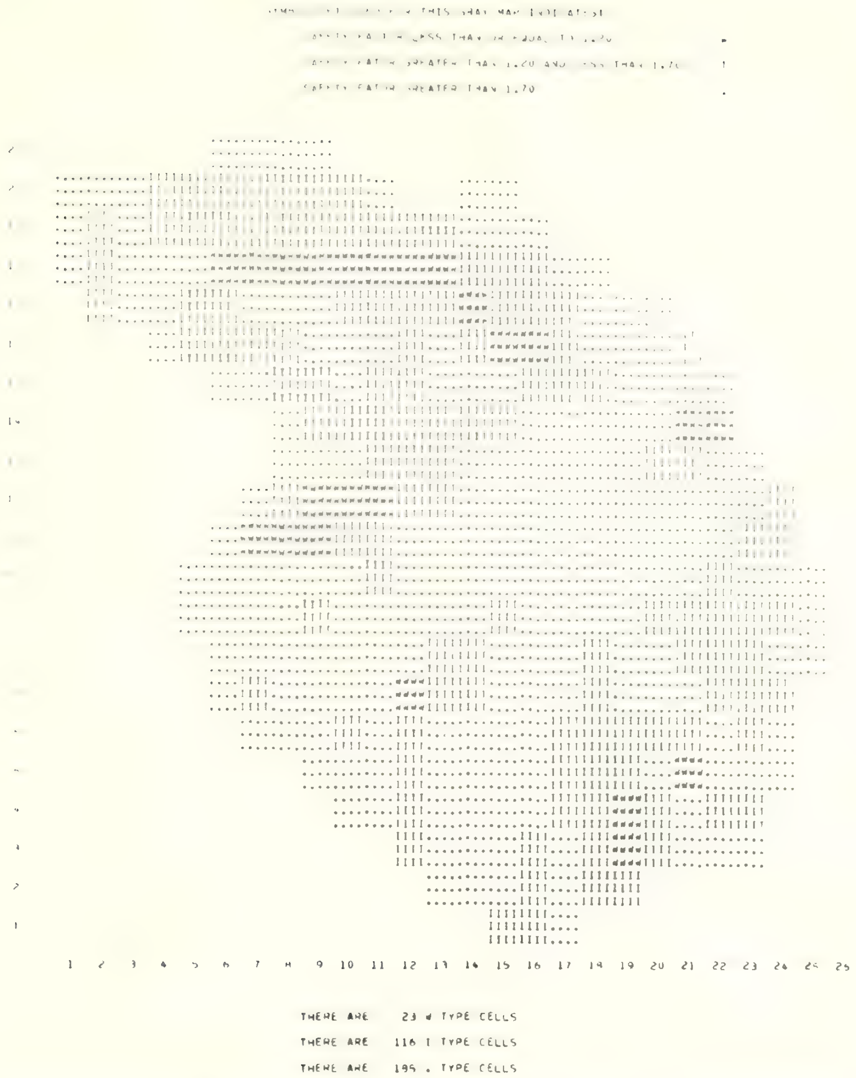
SYMBOLS USED IN THIS GRAY MAP INDICATE:
SAFETY FACTOR LESS THAN OR EQUAL TO 1.20
SAFETY FACTOR GREATER THAN 1.20 AND LESS THAN 1.70 I
SAFETY FACTOR GREATER THAN 1.70 .
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
THERE ARE 23 * TYPE CELLS
THERE ARE 116 I TYPE CELLS
THERE ARE 195 . TYPE CELLS

Figure 3.—Gray area or print density map of Starfish Creek, Alaska, showing changes in factors-of-safety resulting from 100 percent reduction in timber density (entire area clearcut).

analyzed using a cellular approach, the cells can be ranked and then printed (on paper or on a CTR) as a print density map with the high potential (or probability) cells shaded more strikingly than the other, lower potential, cells.

Example

An example of the geotechnical approach was presented by Ward and others (1980, 1982). The methodology was initially tested on a forested watershed in the Cascade Range in Oregon (Simons and others 1978), and has been applied in the Coast Range of Oregon (Ward and others 1980). The example is for a basin located in the northern portion of Chichagof Island, southeast Alaska, and is referred to as Starfish Creek. The basin was segmented into 324 10-acre cells, and information from the USDA Forest Service, Alaska Region, Integrated Resource Inventory, was utilized to produce vegetation and soil maps that were grouped into seven soil types and six vegetation types.

Groundwater levels were arbitrarily fixed at 1 and 2 feet, and timber removal at baseline (no removal), 30 percent, 50 percent and 70 percent canopy cover removal, and clearcut conditions. Root strength in the cut portions was reduced to 20 percent of the assumed original value to represent root decay with time (4-5 years).

The results for the baseline and clearcut conditions and 1-foot ground-water level are shown in figures 1-4 as factor of safety (FS) and probability gray-area maps. The darker shades of gray (print density) on those maps indicate more hazardous cells than do lighter shades of gray.

Information presented in the figures can aid planning. For example, the hazardous cells caused by clearcutting can be detected, and areas delineated as unstable can be avoided, another cutting scheme applied, or further investigation initiated.

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SYMBOL SET USED FOR THIS GRAY MAP INDICATES:
     PROBABILITY OF SLIDING HIGHER THAN 90 PERCENT                                  W
     PROBABILITY HIGHER THAN  60 PERCENT AND LESS OR EQUAL TO 90 PERCENT            N
     PROBABILITY HIGHER THAN  30 PERCENT AND LESS THAN OR EQUAL TO  60 PERCENT      I
     PROBABILITY HIGHER THAN 0 PERCENT AND LESS THAN OR EQUAL TO 30 PERCENT         =
     PROBABILITY OF SLIDING EQUAL TO 0 PERCENT                                      .
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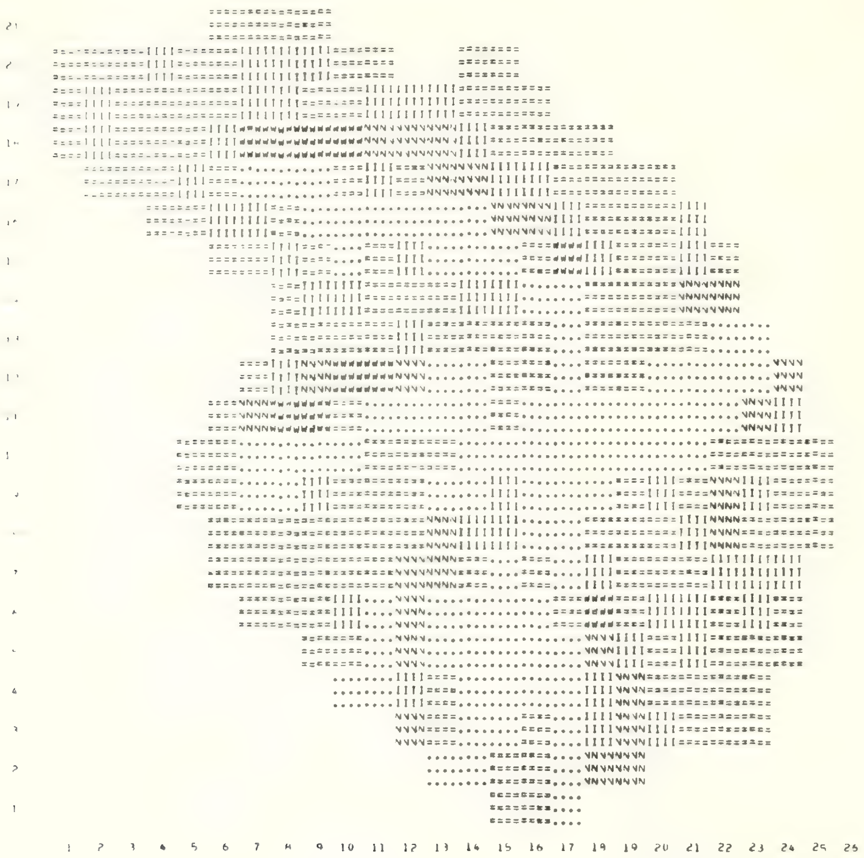

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THERE ARE    10 W TYPE CELLS
THERE ARE    27 N TYPE CELLS
THERE ARE    53 I TYPE CELLS
THERE ARE   151 = TYPE CELLS
THERE ARE    83 . TYPE CELLS
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Figure 4.—Gray area or print density map of Starfish Creek, Alaska, showing changes in probability of failure resulting from 100 percent reduction in timber density (entire area clearcut).

WHAT NEXT?

A phrase for the 1980's is "management technology." What this means is use of the new technologies for the enhancement of management productivity. The concept extends to management planning in that the management planning function will incorporate many of the rapidly appearing technologies. A prime example is the microcomputer. This sleek looking, ergonomic device is changing the way business is done. Such a device, when properly configured, can be used to:

1. Access data on landforms, soils, and vegetation from centralized data banks.

2. Search for references on the area being studied.

3. Accept and store data from field or office test instruments.

4. Load data to a larger, faster computer for processing, then retrieve the results.

5. Process the what-if questions and display the results on the CRT or in print form.

6. Set up summary tables showing results.

7. Act as a word processor to type the planning report.

8. Send the report to a central location.

It is evident from the above limited list that the new technologies will extend the present landslide delineation and risk assessment procedures beyond printing a few maps to a total computer-integrated management planning basis.

CONCLUSIONS

Past and present research has produced numerous techniques to aid in management planning. These techniques often take the form of computer based models of a forest system. When used as an aid the results from such models can be quite helpful. Care should be taken, however, to see that knowledgeable people have the responsibility of applying the model and interpreting the results. The future of such aids is positive. As the computer based methodologies gain wider use, they will become (or be made) more user friendly and less susceptible to misinterpretation.

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A SERENDIPITOUS INTEGRATION OF RESEARCH WITH MANAGEMENT NEEDS: THE BRITISH COLUMBIA FISH/FORESTRY INTERACTION PROGRAM

V. A. Poulin

ABSTRACT: Research in the Fish/Forestry Interaction Program was initiated in 1981 by the British Columbia Ministry of Forests, British Columbia Ministry of Environment, and Canada Department of Fisheries and Oceans as a positive action toward resolution of conflicts concerning steep-slope logging and integrated management of fish and forest resources on the Queen Charlotte Islands. The overall objectives of the program are directed at understanding harvest impacts on fisheries habitat and forest sites, minimizing logging-induced slope instability through the use of alternate logging methods, and mitigating damage caused by landslides using stream and forest site rehabilitation techniques. The program consists of four component research projects, which are being carried out in phases over a 5 year period. The research components are closely integrated within two broad categories of study: (1) impact studies that document the fish habitat damage and loss in forest site productivity caused by soil mass movements; and (2) prescriptive studies that assess the suitability of alternative techniques for reducing slope instability caused by logging and rehabilitation of stream and forest sites following damage by landslides.

INTRODUCTION

Several months ago Doug Swanston called and asked if I would accept an invitation to talk at this conference about the Fish/Forestry Interaction Program. I was not only delighted by the invitation but very pleased to have the opportunity to talk to such a large and diverse audience.

Everything was fine until Doug suggested the title for my talk: "A Serendipitous Integration of Research With Management Needs." When he asked over the phone how that sounded, I said "great," not wanting to reveal my ignorance. I hadn't the faintest idea what the word "serendipitous" meant.

Who had ever heard of Horace Walpole - an English novelist who about the time of the American Revolution coined the term "serendipity" to describe a faculty possessed by the heroes in a Persian fairy tale called, "Three Princes of Serendip." This faculty was the apparent aptitude for making fortunate discoveries quite by accident. In a colloquial sense we're now using the word "serendipity" to express a happy, symbiotic relationship.

In actual fact, the Fish/Forestry Interaction Program originally set out to study the effects of mass wasting--landslides, debris torrents, and so on on fish habitat--and accidently came upon a fortunate discovery: how to fund, staff, and maintain a comprehensive and integrated research

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program in an era of government cutbacks. A difficult task even in the best of times.

Much of what has been and will be said during the conference will point to the need for further work--be it basic research or technology transfer. In any event, perhaps decisions will be made to initiate additional studies and steps will be taken to seek the funding for these projects. I feel the integrated approach our program has taken may interest you and could serve as a role model for efficient use of your research dollars and existing expertise.

This conference has been designed to give us a fresh perspective on the status of research and new findings. Our program is still in the midst of data collection and analysis and, therefore, conclusions are still to come. I would like to explain the purpose of the program and give you some idea of the problems being addressed and the information being collected.

THE RESOURCE

The Queen Charlotte Islands are located off the northwest coast of British Columbia. The islands have a land area of about 10,000 km^2 and were extensively glaciated during the last glacial period. Rainfall varies considerably from west to east, ranging from over 4,500 mm in western fiords to 1,200 mm on the eastern slopes. Steepening of mountain slopes through glaciation, and erosion and weathering of bedrock and glacial deposits are major factors that have resulted in mass wasting being the dominant geomorphic process on the islands.

The predominant timber species are Sitka spruce, western hemlock and western red cedar. In recent years, the Queen Charlotte land base has contributed in excess of 3 percent of the total Provincial harvest on approximately 1.7 percent of the Provincial land base. The Queen Charlotte Islands are extremely productive, and in bottomland areas growth in excess of 1 m annually in height is common. The principal silviculture system used is progressive clearcutting followed by natural regeneration and, in some areas, commercial planting.

Of some 350 streams on the islands, 200 are known to contribute to commercial fish production. Total salmon escapement is estimated at roughly 1 million annually. In relation to the rest of the Province, the Queen Charlotte Islands contribute substantially to the overall escapement by providing spawning area for about 13 percent of the total. Coho salmon, a species that resides in Queen Charlotte streams for one or more years, accounts for nearly 18 percent of the total estimated Provincial coho escapement.

Of the three principal species present, pink salmon are by far the most abundant. The Queen Charlotte Islands also support some of British Columbia's finest steelhead and cutthroat trout fishing. Although most major sport fishing streams are large systems, not directly affected by landslides, many of the smaller, first order streams contribute to trout production.

THE ISSUES

Slope stability problems are not unique to logging on the Queen Charlotte Islands. Owing to a combination of steep slopes, highly erosive bedrock, shallow soils, and high rainfall, natural failures are common and reoccurring.

It wasn't until the late 1960's when most of the bottom land timber was depleted that logging began on steep sidehills and soil stability problems were recognized as a serious concern. Steep sidehill yarding introduced the widespread use of unimproved, midslope roads, most of which were constructed using tractors. Many of these areas are now very active and are a chronic source of sediment and debris to streams.

In autumn of 1978 attention throughout Canada was focused on the Queen Charlotte Islands and its slope stability problems. A major rainstorm hit that caused extensive damage and mass wasting throughout the islands. The storm touched off a series of slides in a logged area overlooking Rennell Sound on the west coast depositing sediment and debris into an important spawning stream for pink salmon. A public outcry, mainly from local environmental groups, followed; they demanded logging be curtailed in sensitive terrain. A serious jurisdictional dispute between the Provincial and federal agencies concerning responsibility for habitat protection also arose out of that event.

The outcome of the situation at Rennel Sound was an agreement between the three agencies--Ministry of Forests, Ministry of Environment, and Canada Department of Fisheries and Oceans--to establish a cooperative framework for dealing with steep-slope logging problems. Part of this resolution was an agreement to undertake a joint interdisciplinary study aimed at applied problem solving.

A task force was established to aid in developing the research priorities. This task force concluded that:

1. Mass wasting was a natural process on the Queen Charlottes Islands and could be seriously accelerated with existing logging and road construction practices; and

2. On some sites accelerated mass wasting did cause severe and persistent loss to forest productivity and fish habitat.

Echoing similar issues that have been voiced throughout the Pacific Northwest, the task force was particularly concerned that information such as effects of siltation on fish was relatively well documented, but that at the time fisheries biologists had little knowledge of the effects of landslides on fish habitat, and certainly less information on rehabilitating sites damaged by slides. Foresters were equally unsure of the risk of causing a landslide and how to prevent future landslides.

In light of these concerns, the task force recommended the research program focus on four major objectives:

1. Provide documentation on the extent and severity of mass wasting and assess impacts on fish habitat and forest sites,
2. Investigate the feasibility of rehabilitating stream and forest sites damaged by landslides,
3. Assess the use of alternative silvicultural treatments for maintaining and improving slope stability by establishing and maintaining thrifty root systems; and,
4. Investigate the feasibility and success of reducing logging-induced failures through the use of alternative logging methods such as skylines, helicopters, and logging planning.

PROGRAM TIMING

The above objectives drive the Fish/Forestry Interaction program. The early expectations were to conduct a 3-year study, but it soon became apparent that this was not enough time given delays in staffing and inexperience in dealing with slope stability issues. We were able to extend the program to cover a 5-year period, which began in 1981.

The work undertaken in the first year was largely directed toward completing a study design, obtaining staff, and initiating background data collection. The second and third years have been directed at extensive field studies. During the remaining two years studies will be concluded and reports written.

PROGRAM ORGANIZATION AND FUNDING

The program is funded by the British Columbia Ministry of Forests, the Fish and Wildlife Branch of the British Columbia Ministry of Environment, and the Canada Department of Fisheries and Oceans. The Canadian Forestry Service, Pacific Forest Research Centre, and the Forest Engineering Research Institute of Canada provide additional support. Total expenditures over the 5-year period will amount to $1.45 million excluding the support provided by participating agencies through seconded salaries and some overhead.

The success of the program to date has hinged largely on the original commitment of the three lead agencies to stress slope stability issues and to prioritize research in the area of applied problem solving. By pooling the resources and undertaking this study, the program has drawn together senior representatives of the agencies in a manner that also provides dialogue and common understanding of research results. It further ensures that senior administrators know the options available and make management decisions based on current knowledge.

The program is organized on the basis of:

1. An executive-level steering committee,
2. A technical advisory committee,
3. A contract program manager
4. A scientific advisory panel; and,
5. Contract and agency project leaders.

The single most important element of the organization structure is the steering committee. The committee consists of senior executives for the Provincial government, the Canadian Government, and industry. This group is the driving force behind the program and is committed to an integrated approach to resolve slope stability problems. The committee meets on an average of once every 4 to 6 months to provide overall policy direction to and monitor progress.

The technical advisory committee is the working arm of the steering committee and consists of district managers and senior researchers from the sponsoring agencies. The committee provides technical direction, reviews working plans and reports, and approves budgets.

Regardless of program size, few integrated studies have the luxury of having internationally renown experts on staff. The Fish/Forestry Interaction Program has asked a group of recognized scientists to help provide advice on project study design and to serve as reviewers for program publications. This group has met yearly with the research team and several scientists have participated in field workshops on the Queen Charlotte Islands. Members of this committe include scientists from British Columbia, Washington, and Alaska.

An advantage of this organizational structure is that project management and many senior project leaders are contract personnel and not part of any agency. As the contract program manager, this gives me the flexibility to cross agency boundaries and cut through administrative detail. I have full fiscal control over the program and administer all contracts and disbursements. This enables me to direct and administer the program on a day-to-day basis with little interference.

As an independent manager, I have the latitude to approach any viable source to gain support for the program. The program has been able to sponsor job creation (volunteer) projects, for example, that have made several labor-intensive studies possible at no cost to the program. In addition, all of the drafting and much of the office support services have been provided free through this job creation approach.

The project leaders report directly to the program manager and because of the flexibility of the program in attracting support, 11 separate studies have been initiated that have involved 14 project leaders. Our project leaders have included:

- researchers from two Provincial ministries,

- post-graduate students,
- senior researchers from industry, and
- contract Fish/Forestry Interaction Program (FFIP) staff.

STATUS OF RESEARCH

To stay within the theme of the conference, I would like to review the studies we have initiated and discuss the nature of the information we are collecting and hope to provide. Up to now our research goals have focused on three major tasks:

1. Developing an understanding of the problem by describing the extent and severity of mass wasting on the islands and the link to timber harvest operations.

2. Assessing the impacts of landslides on streams and forest sites

3. Investigating alternative harvesting systems to minimize logging related mass wasting and to develop restorative techniques to mitigate landslide damage.

DEFINING THE PROBLEM

When the program first began in 1981 there was little data to express the magnitude of the problem. Two studies were undertaken to assess the extent and severity of mass wasting on the Queen Charlotte Islands and relation of mass wasting occurrence to land use. The studies were done at two scales:

1. An overview by the Canadian Forest Service using high-altitude, aerial photographs, and

2. A detailed photogrammetric analysis using large-scale, 1:10,000 aerial photographs from 27 drainage basins.

Results of the slide studies point out that the logging-related slides that kicked off the original conflict at Rennell Sound were not an isolated problem. Using 1:50,000 aerial photographs, about 8,000 slope failures have been identified across the Queen Charlotte Islands (Gimbarzevsky 1983). Given the scale of the photography, this is considered a conservative measure. This study further points out that significant landslide activity (greater than 1 failure/km^2 has occurred on nearly 31 percent of the total land area of the islands. Put another way, it suggests that nearly one-third of the island land area is subject to mass wasting.

To develop an understanding of the relationship of logging land use to the occurrence of slides, 27 study basins were examined using 1:10,000 aerial photographs. Results of this study suggest that landslide frequency in the logged portions of the basins is approximately 10.7 failures/km^2 as compared to 2.8 failures/km^2 in unlogged terrain (Rood, in preparation).[1] This is about a fourfold increase in frequency of failures attributable to logging. The combined data from logged and unlogged areas gives an average frequency of 4.4 failures/km^2 for the study basins. Measurements derived from this photographic analysis indicate approximately 1.89 ha. of bare mineral soil is exposed in logged terrain, as compared to 0.7 ha in unlogged areas.

Sediment volumes produced by landsliding were also estimated from measurements on aerial photographs to help establish the relationship between logging activity on the slope and damage to downstream resources. These data suggest there is a quadrupling of absolute sediment yield due to logging (see footnote 1). If these data take into account the different ages of slides in logged vs unlogged terrain, the increase in debris yield jumps to 20 times the undisturbed rate.

Slides observed in logged areas were categorized as to point of initiation in an attempt to determine the relationship of failures to specific land use. Results of this analysis suggested that gullies and roads accounted for approximately 70 percent of the failures in logged areas. These failures delivered an estimated 87 percent of the released sediment to streams. Logging roads and logged gullies are clearly major sources of mass wasted debris on Queen Charlotte Islands.

Another major question the program is addressing is what happens to the sediment after it enters the stream channel. Two post-graduate students are examining the characteristics of channels to describe the movement and storage of eroded material in streams and the effects of the eroded material on channel morphology. Other studies are underway to examine stream flow responses to rainfall and to examine the fate of fine sediments introduced into streams.

IMPACT STUDIES

A major part of the Fish/Forestry Interaction Program is directed at the effects of mass wasting on fisheries habitat. Over the past two field seasons, staff scientists have begun studies in some 44 streams. The study streams represent a range of logged and unlogged systems, from those that have a high frequency of mass wasting to those with no mass wasting.

Field studies undertaken in the study streams have quantified the effects of mass wasting on fish habitat--as expressed by changes in pool to riffle configuration, amount of large organic debris, gravel composition, and gravel stability. Within most of the study streams, information describing the distribution and abundance of fish habitat was collected to examine the relationship of fish densities to amount and quality of available habitat. The fisheries data is still undergoing analysis and results are unavailable.

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[1] Ken Rood, Fish/Forestry Interaction Program and Department of Geology, University of British Columbia, Vancouver, British Columbia. Manuscript in preparation.

Outcomes of the fisheries studies will provide information on amount of habitat lost from mass wasting and will document changes in habitat conditions that influence success of fish rearing and egg incubation. Recently initiated fishery studies are examining juvenile salmonid overwinter survival in streams damaged by landslides. These data will assist in defining losses in production attributed to mass wasting.

For the past two summers, the Canadian Forest Service has been investigating the rate and pattern of vegetation succession on slides to ascertain the implications on forest growth (Smith, and others 1983). To date, 45 slides ranging in age from 1 to 125 years have been sampled.

As with other data, the extreme variability in the terrain conditions has made clear trends difficult to distinguish; however, several general facts have emerged. It takes three to four times as long for a slide surface to reach 80 percent cover as it does for a clearcut logged area. A logged area on the Queen Charlotte Islands, for example, will usually reach 80 percent cover in 26 years as compared to 85 years on adjacent slide terrain. When a slide is treated separately, however, the figures change. The upper one-third of a slide barely reaches 80 percent cover in about 100 years; in the lower one-third that level is reached in just 30 years, or close to the average in logged areas.

Red alder appears to be the greatest single determinant in vegetation succession on most slides. When alder occurs in high densities, such as the lower one-third of slides on low-elevation sites, it dominates other vegetation for 30 or 40 years. After that, alder begins to deteriorate, allowing conifers--but often sparsely stocked conifers--to attain an increasing share of the canopy.

In areas where alder hasn't become established, such as high-elevation sites and in the upper portion of slides, conifers--particularly Sitka spruce and western hemlock--dominate. These patterns of the successional forest growth suggest that while acceptable revegetation is obtainable on the lower one-third of slides, these sites still fall behind vegetation establishment in clearcut units. The middle to upper parts appear to remain open to surface erosion and gullying for considerable time.

PRESCRIPTIVE STUDIES

Field studies are being conducted by the Forest Engineering Institute of Canada to determine how best to log the Queen Charlotte Islands to reduce landslide impact using new or traditional systems and to develop logging planning techniques for marginally stable terrain. Studies to date have primarily been reviews of alternative yarding systems and have provided background field data on logging planning. Field studies this past summer have been directed at examining the effectiveness of skyline systems for logging in gullies. In addition, approximately 100 landslides included in the aerial photography surveys were examined by logging engineers to establish cause and effect relationships.

A literature review of hillslope restoration practices is being done to suggest management techniques for the Queen Charlotte Islands. Budget limitations have not permitted pilot studies, yet a small, slide revegetation project was initiated this spring involving the planting of some nine different varieties of shrubs to obtain an indication of their suitability for revegetating slide and browse damaged areas.

A review of short- and long-term silvicultural options for improving slope stability following logging is underway. It is hoped this work will identify possible techniques for improving slope stability and culminate in field research.

An important aspect of the Fish/Forestry Interaction Program studies is determining how to restore streams damaged by slides. The several projects undertaken include examining the use of steel gabions to improve salmon spawning areas, and replacing log debris in streams to develop rearing habitat. Three gabion barriers were placed in a stream in the islands by using heavy equipment and hand labor. Our initial impression of the structures is that they are costly but may be effective in increasing fry survival. The study needs to be completed this winter to evaluate costs and benefits.

Our other study involved the replacement of 25 pieces of log debris in a stream heavily damaged by a debris torrent. The objective of the project was to determine if simple log placements in a stream could speed natural recovery of a stream following a torrent. Preliminary observations of scour pools created over the past winter suggest habitat complexity is increasing, and a definite pattern of increased pool area and meander length is emerging. The use of log barriers appears to be a promising technique that is much less expensive than artificial structures such as gabions.

CONCLUSION

The Fish/Forestry Interaction Program is compiling a significant data base on the Queen Charlotte islands that will enable managers to better understand the risk associated with steep-slope logging and effects on streams and forest areas.

The final results of the program will provide a clearer picture of the link between downstream channel responses and logging and help determine where and how to log marginally stable terrain within some level of acceptable environmental risk. An important task is working with industry and other user groups to ensure that the results of the program help to better manage the forest base.

The most important point I can convey to this audience is that joint ventures between cooperative agencies do work and work extremely effectively.

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HARVEST PLANNING AND LAYOUT ON STEEP TERRAIN--THE SIUSLAW MODEL

George Bush

ABSTRACT: In the early 1970's, the Oregon Wildlife Commission and several other special interest groups openly charged the Siuslaw National Forest with causing significant damage to fish and water resources as a result of harvesting of unstable slopes. Without local research data or any dependable theoretical models to apply to the problem, the Forest launched into one of the most intensive empirical modeling efforts ever made on unstable lands. The method used was based on the premise that inventoried landslides associated with specific management impacts on lands with carefully defined physical characteristics can be depended upon to occur in the future, providing management impacts and climatic parameters are similar.

INTRODUCTION

The United States Federal District Court in Eugene, Oregon will soon rule on the case of the National Wildlife Federation vs. USDA Forest Service (Mapleton Ranger District). The substantive issue in that case centers around the impacts of timber management on slope stability and ultimately on fish, water, and soil resources. The Forest's ability to prevent unlawful mangement-associated landslide damage was challenged. Part of the answer to that challenge was a display of modeled projections of landslide damage. The Forest argued that the data showed present and future reductions in impacts from what has been experienced, and that the damage would not be major. The Siuslaw's sophisticated modeling of future consequences of accelerated landslides is central to the defense of existing and planned timber harvest activities.

The real importance of this case is not just the ruling itself, but the apparent effect that legal recourse by dissatisfied interest groups will have on the Forest Service's attitude and approach to slope stability problems. Managers of unstable lands can no longer wait for perfect methods to analyze the problem and, of course, ignoring the problem is not an option.

This paper outlines the Siuslaw National Forest's approach to understanding and coming to grips with management effects on slope stability and the resulting impacts on Forest resources. The method is straight forward and simple, and very quickly provides basic answers to basic problems. The method is not entirely accurate, but can be very precise; and, in my view, precision is the most important element in comparative analysis of alternative actions. Other modeling methods may be used in conjunction with this one to increase accuracy, but the time to start modeling is now. The Siuslaw's method may be the best way to gain quick and defensible information on management-related impacts to unstable lands.

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HISTORY

The Siuslaw National Forest went from knowing nothing, to suspecting something, to systematically analyzing evidence of landslide impacts over 11 years. Energy for doing something finally came from direct confrontation with the Oregon Wildlife Commission in May 1974. That was a period which I suspect Dale Robertson will not soon forget. As Forest Supervisor, Dale and his staff brought the Forest out of the dilemma in which it found itself by guaranteeing committment to solve the management problems on unstable lands that concerned the Wildlife Commission. The Siuslaw National Forest responded in this way for two reasons: first, sufficient external pressure was exerted on the status quo; and second, strong, focused leadership both then and now has demonstrated that only strong solutions to resource damage are acceptable regardless of the effects on the status quo, including timber targets.

First priority after setting the objective was proper staffing to attack the problem. Several soil, water, and fish specialists arrived and began working on finding ways to (1) understand, (2) display, and (3) mitigate or prevent the management impacts on slope stabilty and associated resource damage. No realistic theoretical models existed, so the empirical approach that uses evidence of past management effects began to develop.

METHOD

The method developed was based on the logic that landslide processes accelerated by particular management activities on carefully defined landforms will accelerate in the future at a similar rate providing the management impacts and climatic parameters are similar. If there is any segment of history which repeats itself in a regular way, it is the reaction of geomorphic processes to environmental changes. By merely recording landslide rates associated with current management impacts without attempting to understand the interaction of the myriad of variables that caused them (as theoretical models attempt to do), the empirical modeler can effectively predict future landslide rates while avoiding some of the pitfalls of having a less than perfect understanding of all the processes involved.

Much of the data necessary to understand and display the effects that harvest and road construction activities have on slope stability already existed when the modeling effort began. It had unknowingly been recorded on resource aerial photos. A prototype aerial photo inventory of landslides visible in clearcuttings on 1972 resource photos was made in 1975. The first approach used the existing Soil ResourceInventory mapping and stability interpretations[1] as a tool to begin to organize the landscape into high-risk and low-risk components. Each landtype delineation defined significant geologic and soil patterns that were linked intuitively to relative erosion potential. These qualitative interpretations of relative risk of landslides following clearcutting later proved to be accurate for all but a few of the more subtly unstable landtypes. This high level of accuracy was no accident. The risk analysis by the soil mappers was based on a basic understanding of geomorphic processes. The major difference between what the soil survey people did in making their interpretations and what the Siuslaw National Forest staff specialists have done since is systematization of the landscape and hazard rating processes, and utilization of more site specific data on landslide rates than had originally been accessible.

This first landslide survey, then, was used to determine the number of landslides per unit area clearcut in the most unstable lands on the "high risk" or most unstable landtypes. Average volume of landslides was determined by measuring length and width on the photos and assuming an average depth. A relative comparison of increased landslide rates within clearcuttings was made between alternative harvest schedules and levels of mitigation and prevention techniques in the 1978 Ten Year Timber Resource Plan[2]. Road slides were initially ignored in the inventory and modeling process for two reasons. First, road slides had received intense interest for several years, and pressure to change had resulted in significant changes in design, location, and maintenance. The Forest felt it was correct in solving or mitigating road slides. Second, clearcut harvest-associated slides was a new concept to most of the Forest management team, who required the majority of available time to understand the magnitude of the problem and the potential for prevention or mitigation.

LANDSLIDE PREVENTION

Knowing expected landslide frequency per acre clearcut is only half the information needed to make planning decisions. The planner must also know how prevention or mitigation techniques will affect decisions about land allocation and harvest scheduling.

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[1] Legard, Harold; Meyer, LeRoy; Badura, George; Boyer, Don. 1974. Soil Resource Inventory, Siuslaw National Forest, U.S. Department of Agriculture Forest Service, Pacific Northwest Region. Copy on file at Siuslaw National Forest, Corvallis, Oregon.

[2] 1978 10 Year Timber Resource Plan, Siuslaw National Forest, U.S. Department of Agriculture Forest Service, Pacific Northwest Region. Copy on file at Siuslaw National Forest, Corvallis, Oregon.

Predicting the reduction of accelerated landslides in clearcut units has been a major part of the modeling program at the Siuslaw. Landslide prevention techniques, whether for roads or timber harvest, are based on the premise that loss of internal soil strength resulting from management activity increases the potential for erosion (landslides).

In clearcuttings, loss of root strength is the major factor influencing accelerated landslide rates. Therefore, leaving the vegetation undisturbed on those sites most likely to require the added strength of the root system to prevent slope failure is the only practical way to reduce clearcutting-associated landslides. The Siuslaw landslide model predicts the reduction in accelerated slides by estimating the future effectiveness of vegetation leave areas in preventing landslides. Theoretically, if all sites that would fail because of lost root strength were left uncut, no accelerated slides would occur. Implementation of such a perfect program is clearly not possible. Several factors, including identifying and locating unstable sites, and logging, fire, and wind damage to vegetation leave areas reduce the implementation efficiency of the leave areas. Some percentage of accelerated slides occur regardless of best intentions. Reliable modeling of reduction of landslides by leaving unstable areas uncut requires an estimation of the influence these factors have on reducing the effectiveness of leave areas.

Estimation of efficiency of vegetation leave areas has been one of the weakest parts of our modeling process. Without much experience in using vegetation leave areas on unstable sites, there is little practical evidence to rely on. The only short-term solution has been to use professional judgment of field personnel to estimate the probabilities that leave areas will be effective. The estimates for each factor when multiplied together has resulted in approximately 50 percent efficiency for vegetation leave areas. Specialists applying this technique feel this is very conservative, but only several years actual experience with leave areas will provide us with an accurate accounting of the effectiveness of this practice. Putting off implementation until better information was available would result in no use at all. Only practical, on-the-job use of vegetation leave areas on unstable sites will ever lead to understanding their value. I wish more Forests would attempt to use the leave area concept so the knowledge would be strengthened and broadened. The trade off in timber harvest potential where leave areas are used is obvious: every acre left uncut to prevent landslides is removed from the productive timber base. Using the landslide model as a tool to project acres of vegetation leave areas necessary to meet minimum resource protection requirements, we are projecting approximately 15 percent of the productive base allocated to no harvest.

EFFECTS ON OTHER RESOURCES

During the early stages of the modeling process, the effects landslides had on other resources including water, fish, and soil productivity were not clearly understood. The effects on fish habitat were estimated in a primitive model that predicted changes in fish habitat because of management accelerated landslides. The model assumed the major impacts of landslides to fish habitat were reduction in quantity of habitat (number of usable and accessible miles of stream) and amount of sediment in excess of natural or background levels. This model, too, had its greatest value in making comparative analyses. Fish habitat, as it was perceived in 1978, was compared, on an index scale, to habitat associated with several alternative management scenarios through 1988. A truely accurate accounting of sediment and other instream effects of landslides was, and is, too elusive to worry about, at least in these early stages of developing slope stability and fish habitat models.

The present generation of modeling has been geared to improving the accuracy of the assumptions used in the landslide and fish habitat models to increase the accuracy of our perceptions of the apparent effects forest management had on slope stablity and ultimately on the fishery resources. By periodic on-the-ground monitoring of landslides on a sample basis, improving the geomorphic classification of the landscape, and doing yearly landslide surveys, we are hoping to better shape our concepts of such things as:

1. Relative importance of road associated slides and clearcutting associated slides;

2. Percentage of landslides contributing to instream sediment;

3. Percentage of slides blocking fish passage;

4. Percentage of slides scouring fish-bearing streams;

5. Variations in landslide frequency resulting from different storm intensities;

6. Variations in landslide frequency between areas which are geomorphically different; and

7. Actual effectiveness of vegetation leave areas for preventing clearcut harvest associated slides.

Random sampling of fish-bearing streams and specific research information on the importance of sediment, organic debris, and fish blockage have also fine tuned the precision of the fish habitat index scale. The assumptions are now more defensible and the relative importance of the various effects of accelerated landslides has been clarified. Predictions of absolute changes in habitat and fish production are still lacking.

APPLICATION TO PLANNING

A fundamental improvement in the application of the Siuslaw slope stability and fish habitat modeling techniques has been the continuing development of the land systems inventory. It is patterned after the systems developed by USDA Forest Service in the Northern and Intermountain Regions. The system we use allows for a hierarchial organization of lands according to similarities in climate, bedrock, dominant erosion processes, landform, soil, and vegetation. The existing Soil Resource Inventory landtypes mentioned earlier have been grouped within the hierarchy to clarify the relative amounts of high- and low-risk lands between major portions of the Forest that have basic geomorphic and management opportunity differences. The system also groups areas similar in fish habitat potential and hydrologic response. Without a solid land systems inventory, landslide surveys and models made from them have limited value in the planning process. Generalization of gross averages of accelerated landslide rates across the Forest is too broad for even forest-wide planning because it masks important local differences. On the other hand, landslide data for each individual landtype is far too specific to be effectively used for most levels of planning.

I stress planning applications for this sort of modeling for several reasons. On-site decisions about management on unstable lands cannot be made with data that does not account for microsite variations. Project or on-site decisions about slope stability always must be made with that magical combination of theory, on-site stability indicators, and undefinable vibrations that come up through the soles of the feet of any qualified slope stability expert.

Empirical modeling of landslides is most successful when important measurable effects of management activities and variations in climate are understood. We are very far from having that sort of knowledge. As the planning cycle repeats itself, monitoring of project implementation efficiency and effects of projects on slope stability is accomplished, and better information on climatic variables becomes available, the precision of the predicted impacts will become better and better. Without a start, even with the meager data available, improvement is a meaningless word. Modeling involves risk, regardless of the technique, but there is greater risk if modeling is not done.

It seems there are three ingredients necessary to successfully develop an effective model of management effects on slope stability: (1) pressure to work on the problem, (2) a way to work on the problem, and (3) committment to work on the problem. The first is painfully here; the second you are hearing about at this symposium; the committment must come through you.

USES OF SOILS, VEGETATION AND GEOMORPHIC INFORMATION FOR ROAD LOCATION AND TIMBER MANAGEMENT IN THE OREGON COAST RANGES

Byron R. Thomas

ABSTRACT: Five major factors affecting slope stability are soil shear strength, soil depth, slope gradient, soil water, and root strength.

Soil shear strength is best determined by engineering tests conducted in the laboratory; however, it may be estimated in the field by using soil survey information in conjunction with conversion charts or by back calculation. Soil depth and slope gradient are determined directly by field measurements or interpretation. Soil water depth may be measured, modeled, or inferred from soil properties and geomorphic location. Root strength is inferred from research data correlating root decay over time since trees were felled.

At a qualitative level, some very effective assessments of occurrence or importance of these factors can be made by careful field observation and the use of aerial photos. Vegetative indicators provide many clues to soil wetness and incipient failures. These include occurrence of hydrophytic species and tipped or "crazy" trees. Bedrock topography that concentrates ground water may be readily identified in the field or with stereo pairs of photos. Geologic features such as fault zones or formations with known zones of weaknesses provide important information about stability to field personnel.

INTRODUCTION

A common type of landslide in Oregon's Coast Range is the debris avalanche or infinite slope failure. Working knowledge of factors contributing to instability and on-site clues for potential landslides is required by those laying out and designing roads and timber sales if these types of problems are to be minimized.

FACTOR ASSESSMENT

To effectively evaluate slope stability, a person needs background information about geology, climate, and soils in the area of interest. For example, geological and soil properties greatly influence soil mantle stability. The failure surface commonly occurs at the soil-bedrock interface or within the soil mantle. Soil shear strength cannot usually be determined accurately without testing. Test results may be extrapolated, however, to areas of similar geology and soils for the purpose of evaluating potential landslide areas. Technical papers and books describe procedures to estimate soil parameters for nonplastic soils. Another empirical method is to measure appropriate factors from existing landslides and solve a

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mathematical equation for shear strength.

Soil water is often the critical key to instability. Landslides occur most often during periods of intense rainfall or rapid snow melt. The reason for this is that water within the soil accumulates over the bedrock surface, or other impermeable boundaries, in hillslope hollows. The result is that the pores in the soil become full and provide an uplifing force on the soil mass as a result of the buoyancy effect. This uplifting force becomes greater as more water accumulates in the soil. This saturated mass is more easily pulled downslope by the forces of gravity.

Many times areas subjected to soil water accumulations may be identified in the field by occurrence of hydrophytic vegetation, soil characteristics, and geomorphic position.

Importance of roots in mantle stability has received considerable attention. It is generally accepted that a network of roots strengthens the soil mantle just as reinforcing bars strengthen concrete. Larger roots also function as piles when they penetrate into cracks in bedrock. When these piles are close enough, they also function to strengthen the slope by preventing soil from sliding between them. Studies have shown that landslide frequency often increases 2 to 8 years after trees are cut. This is the time frame in which smaller tree roots decay and weaken. Decaying roots per se cannot be observed. An inference may be made from time since felling when related to other factors that influence landslides. Conceptually, if soils stay in place in areas that should be unstable or should have already failed, then root strength may be the factor holding the soil mantle in place. Root strength decline should also be considered when portions of clearcut units start failing.

FIELD INDICATIONS

The following photographs show examples of clues to instability that may be observed in the field. An important item to keep in mind is that there are usually multiple clues to potentially unstable areas. Each picture and caption focuses on one clue.

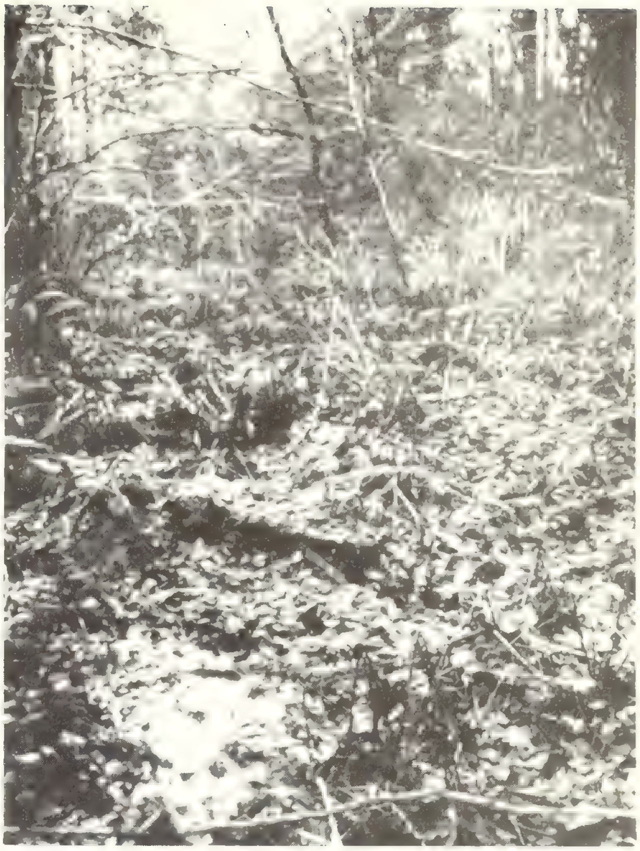
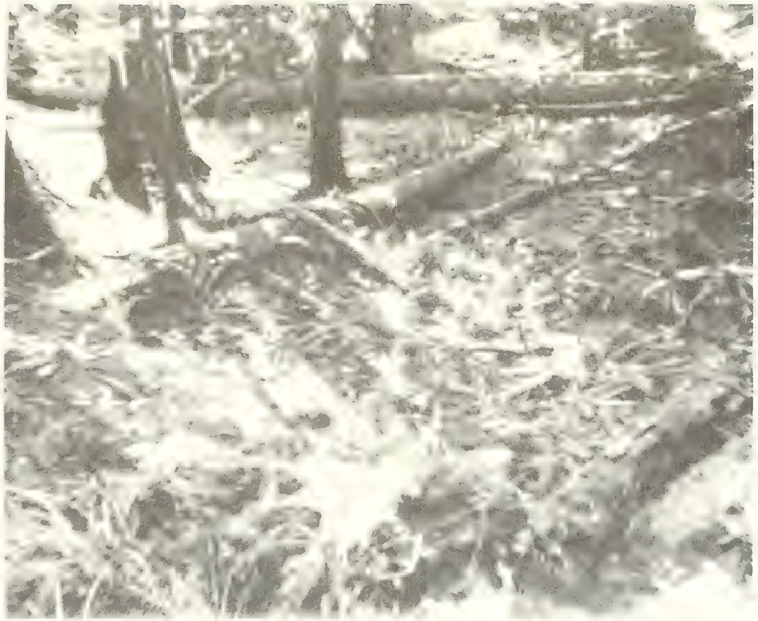
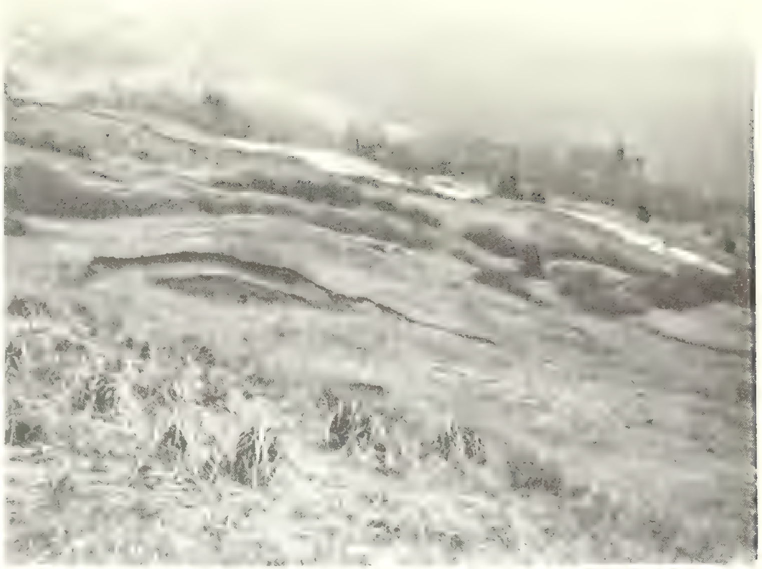


Figure 1.--Seeps and springs. Standing water on the soil surface demonstrates that soil water is at or above the ground level. The entire soil profile is considered to be saturated for purposes of calculating mantle stability.





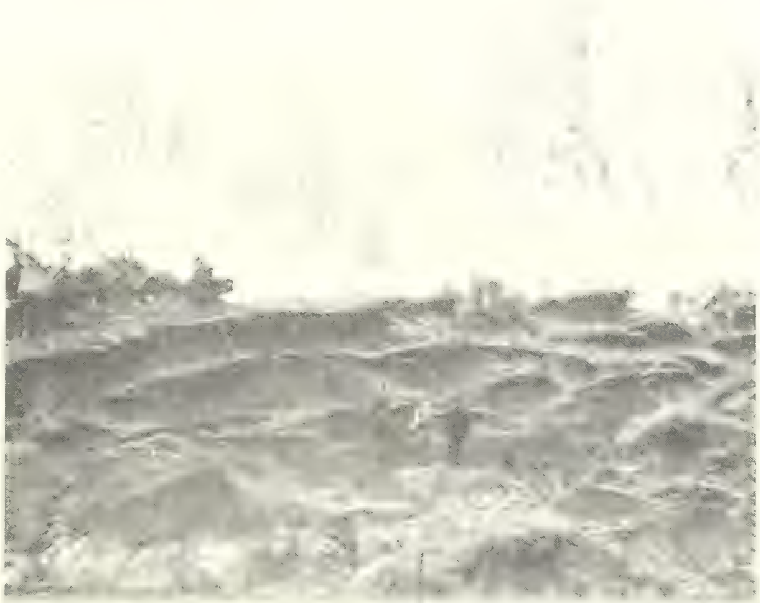


Figure 2.--Presence of hydrophytes (upper left). Hydrophytes indicate high levels of soil water. Hydrophytic species need to be defined locally. For example, a dense stand of sword-fern may denote wet conditions for some geographical areas and not others.

Figure 3.--Meadows (upper right). Natural meadows may be a clue to instability due to soil wetness. One should especially be concerned with those occurring on slopes surrounded by coniferous trees.

Figure 4.--Black soil surface (lower left). Importance of a thick, very dark colored, soil surface needs to be determined locally. These types of surface soils may or may not be important when looking for clues to soil wetness. The black surface is a result of incorporating large amounts of organic matter. A high soil moisture regime is conducive to high vegetative production.

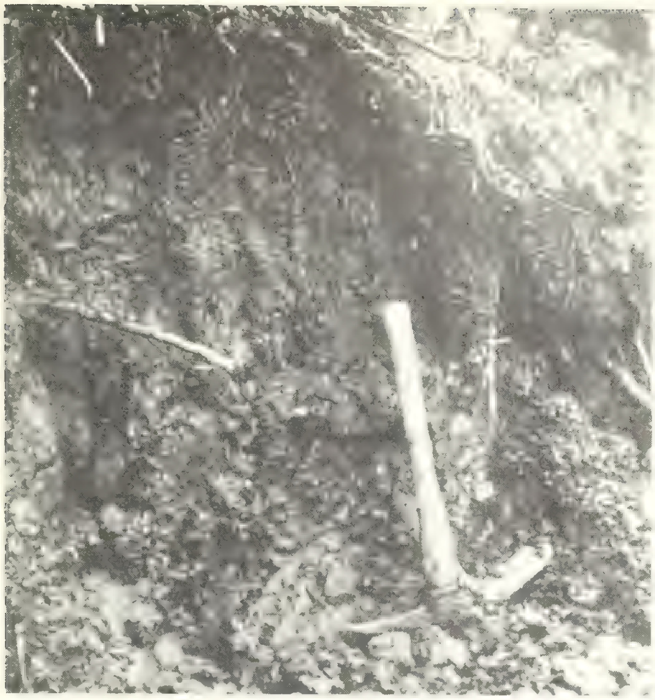


Figure 5.--Gleyed or mottled soil. A gleyed soil exhibits gray or bluish colors because iron is reduced chemically. A high water table usually occurs continuously or for long periods of time annually in gleyed soils.

Mottled soils are similar to gleyed soils except water is thought to rise and fall several times annually. Rising and falling water tables create alternate reduction and oxidation of soil iron. Mottles are characterized by splotches or streaks of gray, red, orange, or yellow. Height of the highest mottle is assumed to indicate the highest annual water table rise. Mottled colors are not continuous in soil, but are quite distinctive.

Figure 6.--Sag ponds. Sag ponds, like seeps and springs, indicate concentrations of water at the ground surface. Sag ponds are created when the hillside slides downslope, rotates outward, and leaves a depression between slump material and the scarp, or back edge, of the failure surface.

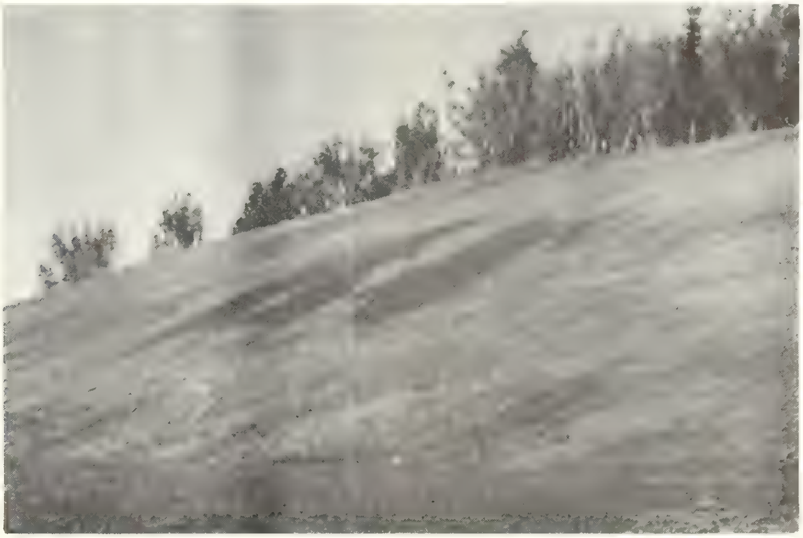
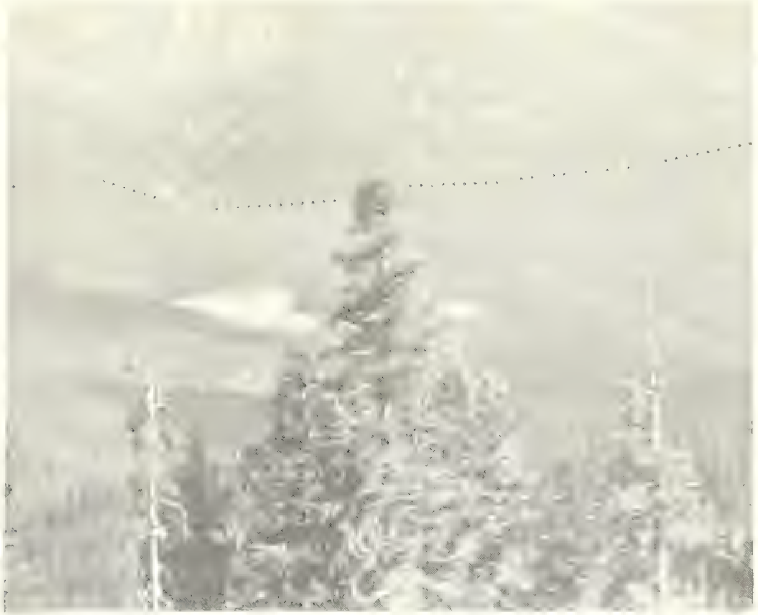
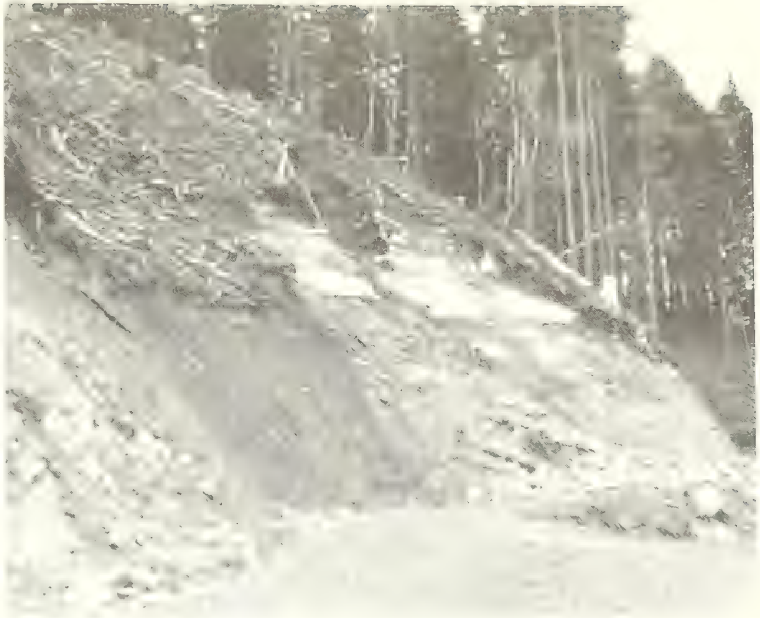


Figure 7.--Piping. Water piping from a road cut or structure shows that free flowing water is being concentrated along open pore spaces within the soil mantle or road prism material. This may indicate the presence of a water table at least as high as the point of exit. It may also indicate a confined zone of concentrated flow under substantial hydrostatic head.





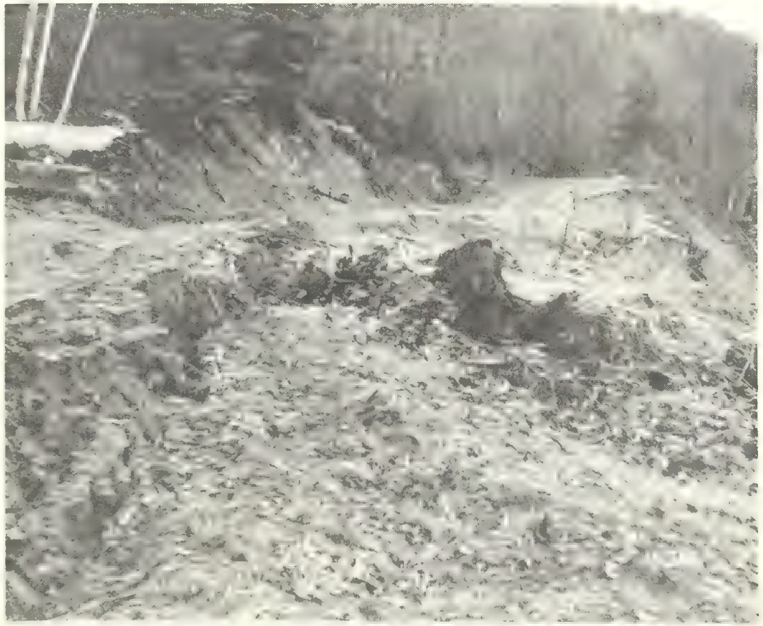
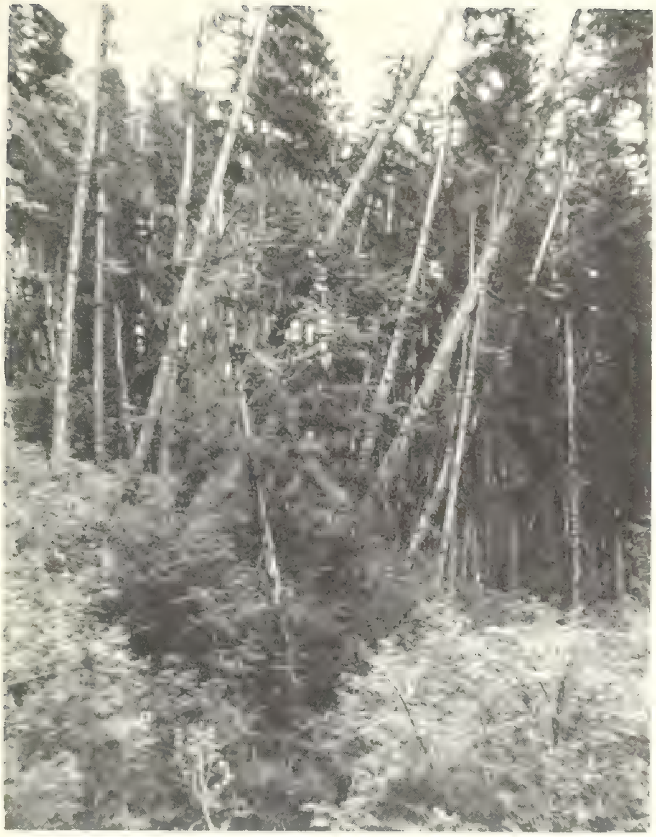
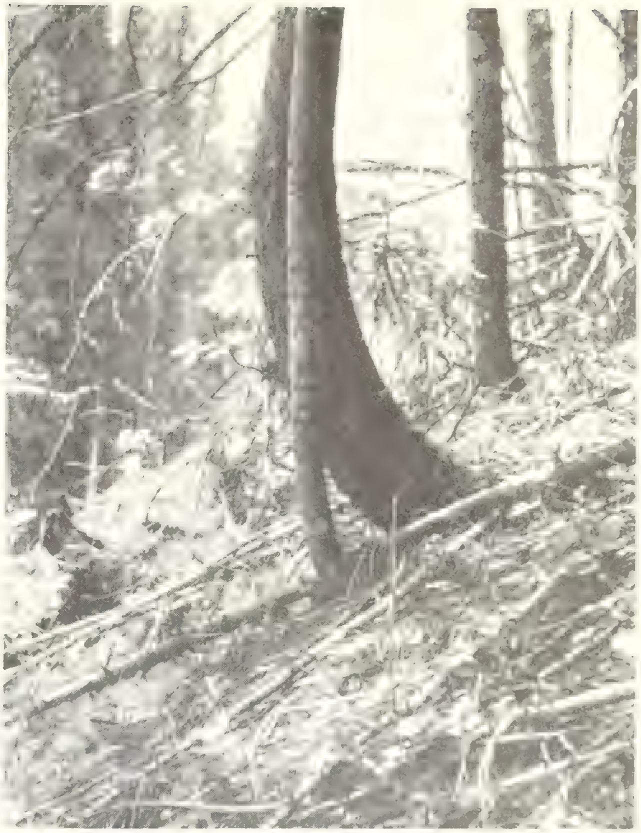


Figure 8.--Fault zones (upper left). Faulting causes bedrock to break and shear, which results in a weakened zone (see dotted line). These weakened zones are often areas of concentrated subsurface water movement and are the source of slope failures, especially when disturbed by road construction. It is not uncommon for the entire road prism to fail.

Figure 9.--Pockets of colluvium (upper right). Competent bedrock is absent in pockets of colluvial material. These "pockets" accumulate ground water from adjacent areas as well as material from soil creep. The surface depression is the only clue to such a situation during field reconnaissance. Not all depressions denote such a situation. Geophysical exploration (seismograph) aids in quantifying subsurface conditions.

Figure 10.--Conglomerates (lower left). Serious stability problems, especially after road construction, occur in conglomerate bedrock in parts of Oregon's Coast Range. Road cuts and fills may slump away. Steep slopes are not a prerequisite for movement in these materials. Not all conglomerates are unstable.





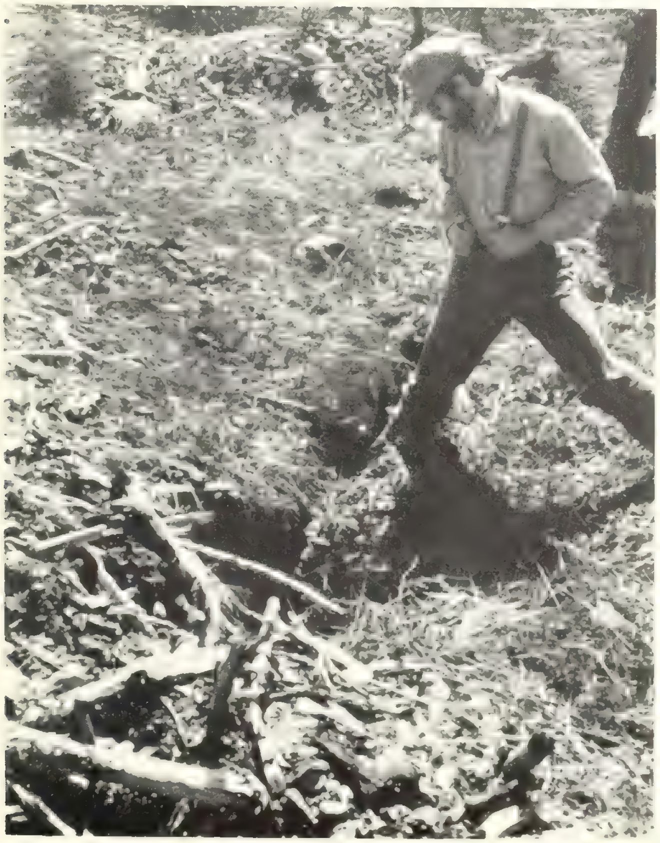
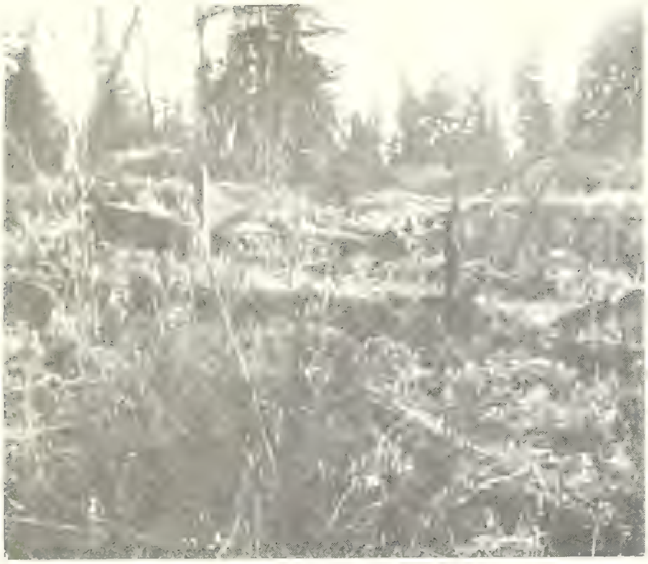
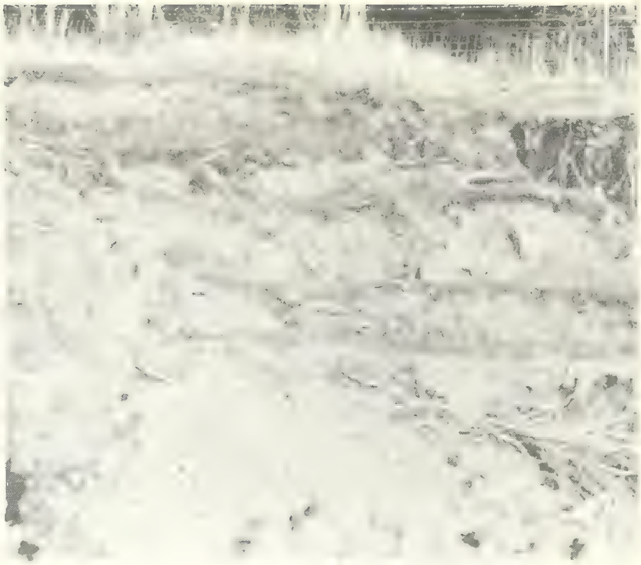


Figure 11.--Tipped, jackstrawed, or crazy trees (upper left). Tipped trees provide solid clues that the mantle is presently moving or has moved during their lifetime. Of course, disturbing an actively moving mantle is risky.

Figure 12.--Curved tree butts (upper right). This clue has to be tempered by additional investigation or knowledge of the area. Butts of young trees also become curved from snow creep. Curved butts in conjunction with other clues or geomorphic location provide a helpful index to stability.

Figure 13.--Tension cracks (lower left). Tension cracks provide physical evidence the soil mantle has slipped and a failure plane has been established. Proceed with extreme caution.





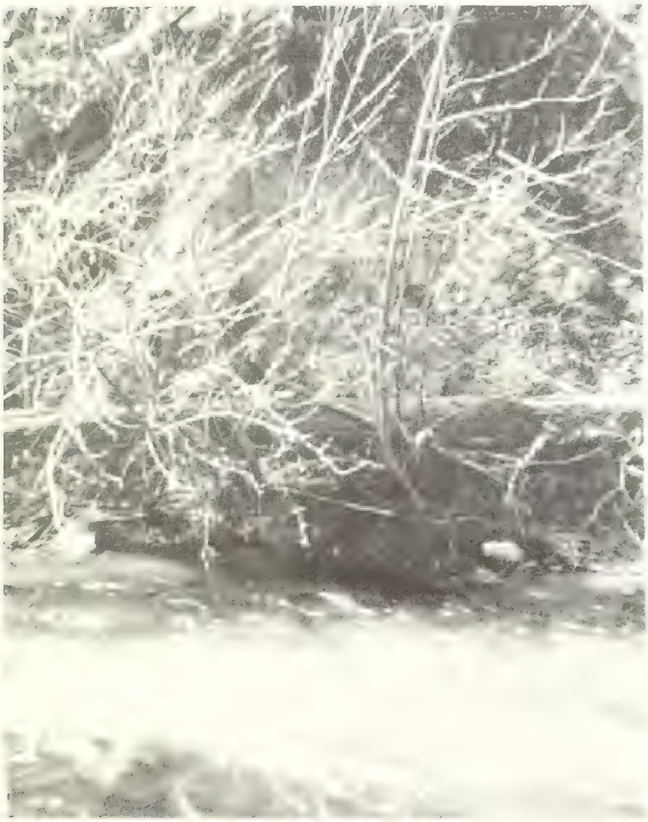
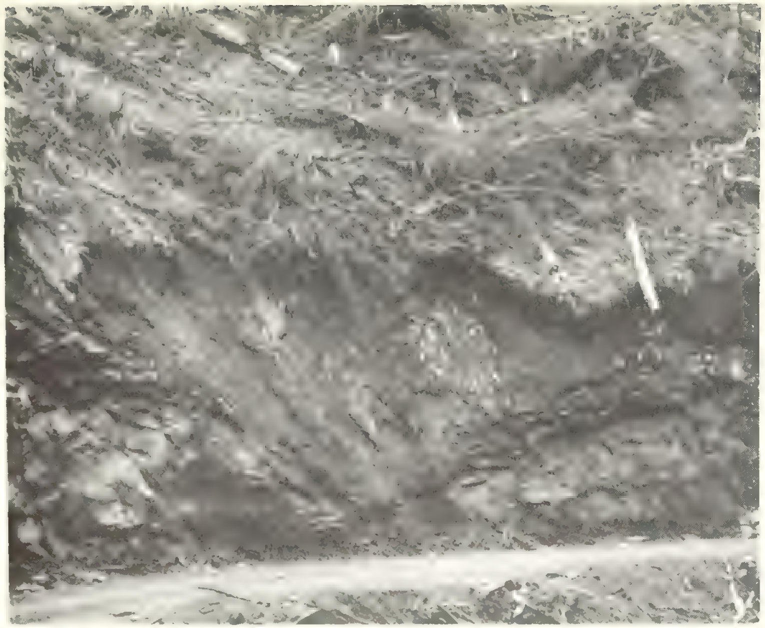
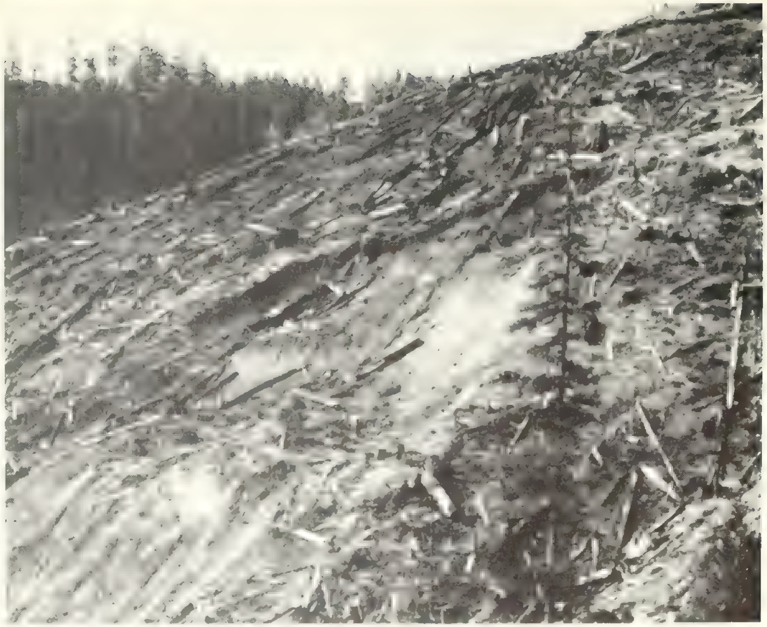


Figure 14.--Hummocky surfaces (upper left). An irregular, hummocky surface shows that the soil mantle has been undergoing forces which cause deformity and movement. These are risky locations for roads without proper investigations and design for the situation.

Figure 15.--Terracettes (upper right). Terracettes are a series of multiple failures. Older terracettes usually have more gentle scarps because the raw, exposed edges have fallen. Again, the clue denotes active movement.

Figure 16.--Streambank overhang (lower left). The item to watch for is the difference between streambank overhang caused by lateral stream movement and soil mantle that is sliding or creeping downhill into the stream. Differentiation between the two at a local site may not be possible. One needs to look at the overall area, particularly upslope. Other clues associated with instability are usually present.





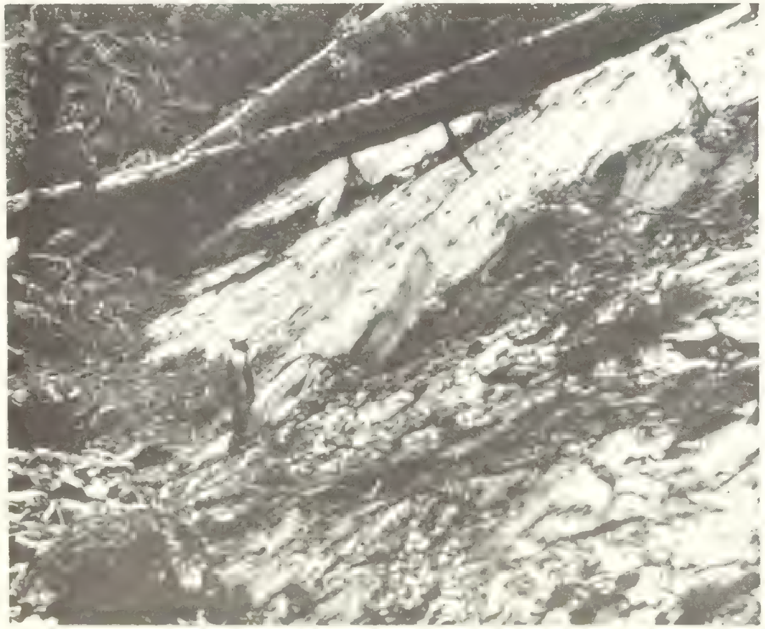
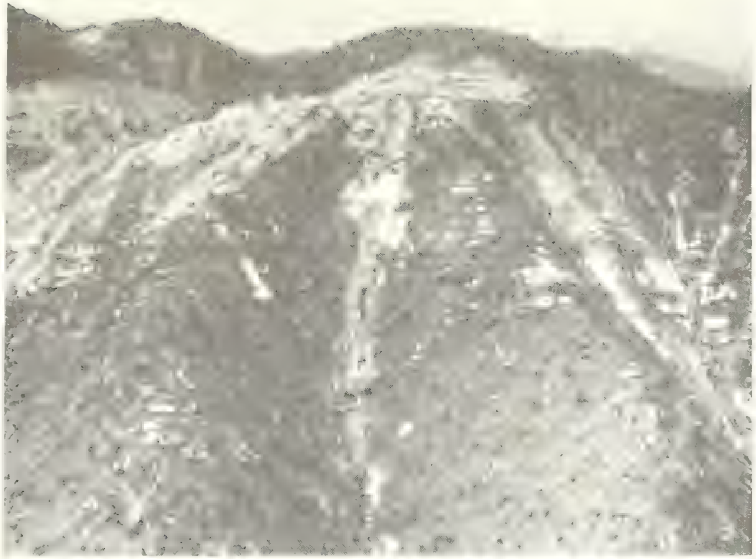
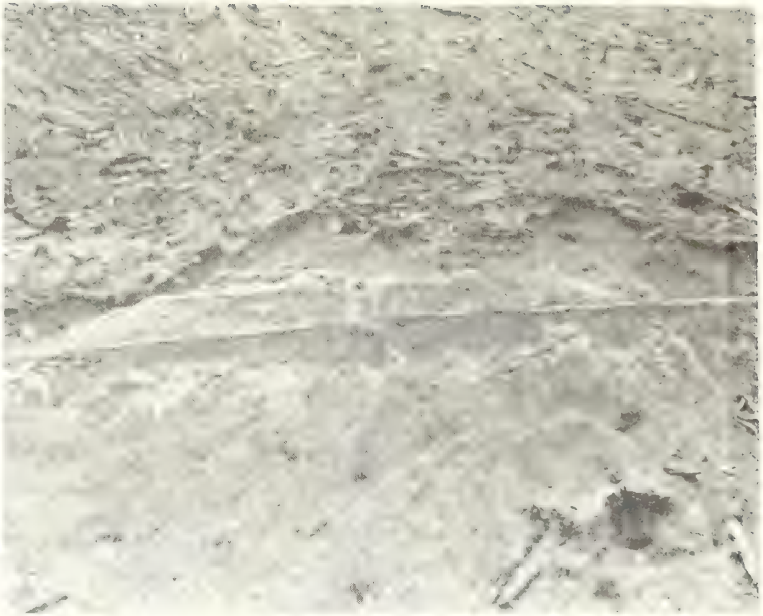


Figure 17.--Downslope depressions or pockets of residual soil resulting from weathering in multiple joints (upper left). (A similar depression is shown in figure 9). Genesis of the two may be different but the surface configuration is about the same. The major item to be aware of is that a depression on a sideslope may indicate a pocket of transported or weathered material. The pocket accumulates ground water, weathers faster, and may lack competent bedrock near the surface.

Figure 18.--Spoon-shaped depression (upper right). It is common for earth flows to be associated with a spoon-shaped depression. Subsidence occurs as the material flows downslope. These areas commonly are acres in size.

Figure 19.--Bedding planes parallel to surface (lower left). Bedding planes parallel to a sloping soil surface are oriented during uplifting of the bedrock. This surface provides a sloping interface of soil and seepage water on top of, and within, bedrock.





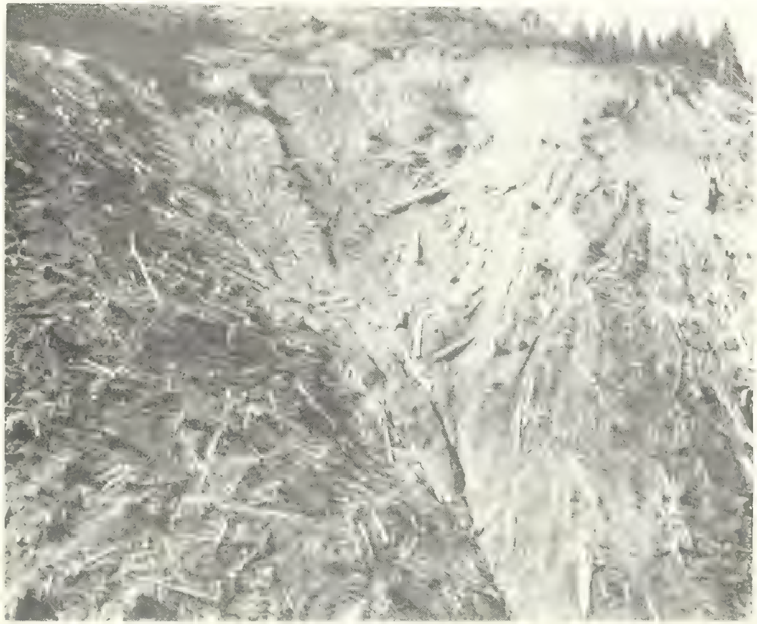


Figure 20.--Very steep slopes (upper left). Some slopes are so steep that soil material is at a critical balance Disturbance by fire, road construction, or logging may cause the mantle to slide. Bedrock is commonly exposed in such areas.

Figure 21.--Old slumps (upper right). Many old slumps have stabilized over geologic time. Removing the toe of these slumps, as shown in the figure, often results in reactivating movement.

Figure 22.--Drainage headwalls (lower left). This figure shows a classic situation where sidecasting in a steep headwall resulted in a slide. Headwalls are very sensitive because of their steepness and ground water concentrations. One would not want to place crossdrain culverts in such positions nor sidecast common material during road construction. Note the backslope has also failed.

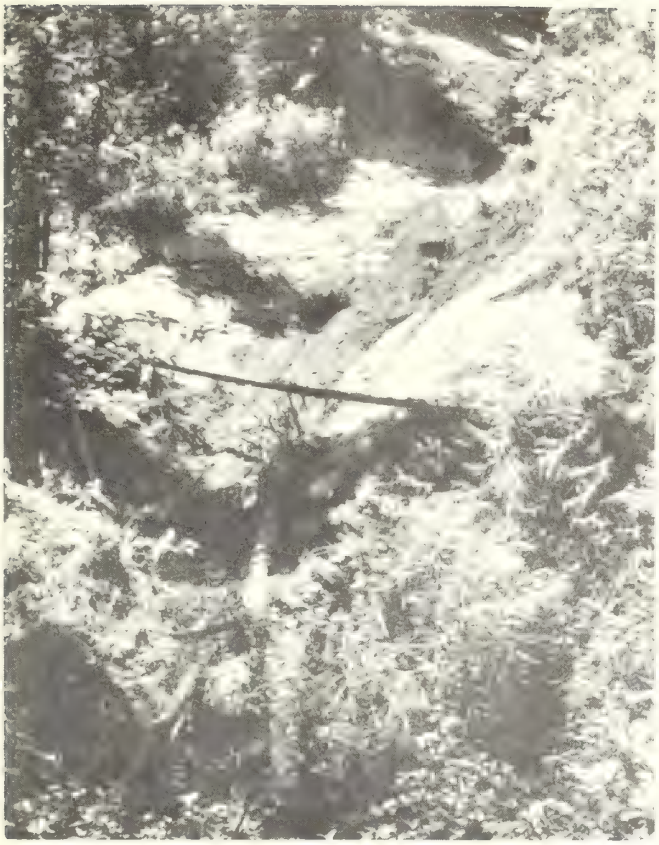


Figure 23.--Failure from accelerated weathering of soil material. Natural weathering of the bedrock does not occur at a uniform rate across a slope. Some spots are weaker (fault zones for example) and form a depression where ground water accumulates. These processes hasten weathering and usually form incipient drainages. Over geologic time, weathered material (soil) or colluvium will slide or wash out. The light areas along the channel in this photo are exposed bedrock surfaces from which soil has been removed by slumping. Note accumulations of soil and debris in the channel bottom. This figure shows how areas shown in figures 9 and 17 look after failure. A "slickrock chute" remains after soil material is removed.

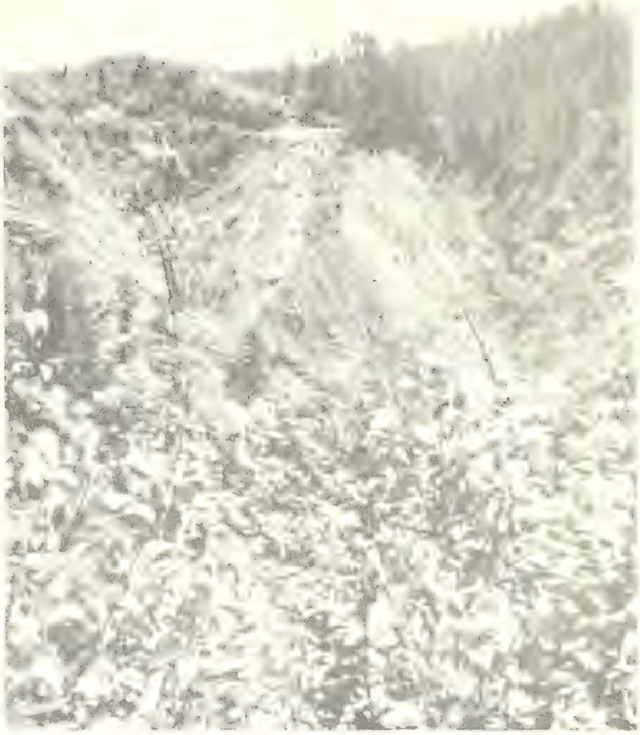


Figure 24.--Land overhang. It is not uncommon for landings to be constructed in such a manner as to have sidecast material form very steep slopes. This is a poor construction practice. This problem is often compounded by piling cull material on the edge. The edge of the landing can fail causing damage on and off site.

ACKNOWLEDGMENT

The author is indebted to Dr. Edward R. Burroughs of the USDA Forest Service, Intermountain Forest and Range Experiment Station, Bozeman, Montana, and various Bureau of Land Management soil scientists working in the Coast Range of Oregon for providing many of the pictures.

ROAD LOCATION IN SENSITIVE WATERSHEDS:

AN INDUSTRY PERSPECTIVE

S. H. Duncan

ABSTRACT: The identification of potentially unstable areas for road location and harvest planning in sensitive watersheds can be done at three levels of resolution. The broadest level involves the use of soil survey or geologic maps and is useful in general identification of particularly sensitive areas. Once the sensitive areas are identified, the second level of resolution recognizes individual landscape units and notes particular slope stability charcteristics as the basis for general management recommendations. The third level must be accomplished on site at the time of road and landing location. At this point, fairly specific construction recommendations can be outlined.

INTRODUCTION

Stability of forest land is a highly valued condition. If all the land were stable, forest practice activities could be pursued with little concern for slope failures. Unfortunately, this is not the case. A large enough portion of Pacific Northwest forest lands are of sufficiently low inherent stability to warrant concern. Although instability of forest slopes has received considerable research attention, most of the studies have emphasized how human activities influence the integrity of the slope and affect mass wasting processes and soil loss. Far less research has been devoted to examining cost effective ways to manage lands of questionable stability. Because of this it is difficult to assess the effectiveness of specific harvesting and road building techniques that have potential as economically and environmentally sound management alternatives. Even less effort has been given to technology transfer and development of credibility with the field engineer or forest manager.

The prudent forest manager knows where the most productive lands are located, how much area is in each site class, and the species compositon of the forest stands on those lands. Because of the interaction of forest management activities with other resources, the forest manager must also be cognizant of unstable lands and the potential environmental and economic risks they pose, and be able to implement realistic management alternatives.

The purpose of this paper is to review a method for identifying unstable lands and implementing suitable technology on them. Emphasis is placed on interaction with individuals, from the tree farm manager to the equipment operator, to develop confidence in current technology and the awareness necessary in economically sound and environmentally effective forest land management. Considerations for future slope stability research and technology tranfer are also discussed.

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TERRAIN CLASSIFICATION

Three levels of terrain classification are beneficial in identifying areas of varying slope instability for harvest unit planning: (1) identification of key soil and lithologic units; (2) identification of specific geomorphic units, which can be assigned relative stability classes; and (3) site-specific identification of potential slope instability along a proposed road location line.

Various terrain classification schemes have been used to identify areas of relative slope stability conditions. Quite often slope stability considerations have been secondary or have been made to fit an inventory system designed for another purpose. The most widely used medium of this type is the soil survey. Although seldom specific enough for detailed identification of slope instability, a soil inventory can furnish useful information on local lithology, soil physical characteristics, and geomorphic units. Broad levels of slope stability can be assigned to these soil inventories, making them useful for broad planning purposes.

The next level of resolution is a more detailed inventory at a scale compatible with local forest or timber sale planning. Such an inventory should identify microgeomorphic units or hill-slope elements (such as concave pockets, seepage areas, and rock outcrops), and local slope gradient. Thus delineated, these terrain units can be assigned relative slope stability designations. When combined with a topographic map, this inventory becomes the basic planning tool for the logging engineer.

Bourgeois (1978) described a terrain inventory system designed specifically for slope stability purposes. Used in western British Columbia, the system incorporates both soils and geomorphic units to which five slope stability classes are assigned and guidelines to minimize environmental impacts are proposed.

Similar systems are in use by governmental and state agencies, but all lack the site specificity often required by the field engineer. Although uniformly desirable, accurate on-site identification of potential stability conditions along a road location line often depend on the specific training of the road location engineer. At Weyerhaeuser Company, a checklist of topographic, soil, climatic, hydrologic, and geologic factors similar to that proposed by Swanston and Swanson (1980) in the WRENS document was developed to assist in on-site identification of potential problems. While far from a prediction system, it enables the road location engineer to consider slope elements and slope-forming processes, thus examining the hill slope differently than he normally would. Once identified, a suspected problem site can be avoided, an extraordinary design implemented, or further study done to assess management alternatives.

Detailed investigations of slope instability are both timeconsuming and costly and can be limited to highly sensitive sites identified in the first level of slope stability identification discussed above.

For the purpose of this discussion, a sensitive area or site is defined as a site consisting of soil and geologic units that are naturally susceptible to slippage where damage to a public resource or private property could occur. This greatly reduces the area of land that need be considered, even though other lands may be classed as sensitive for different reasons.

Many sites that fit the above definition are already known from past experience; if not, an interpretation by someone trained in soil and geology may be required. What is important is that broad slope stability classifications and accompanying "fit-everywhere" interpretations are avoided. They are often as much in error as they are correct and frequently result in unnecessary and costly practices.

IMPLEMENTATION OF TECHNOLOGY

Sensitive area identification, soil and geomorphic mapping, planning, and just plain "geologizing" by technical experts is of little value unless the technology is implemented. The most important part of implementing slope stability technology in forest management is to work with individual managers, engineers, and foremen to develop an awareness and ability to recognize: (1) if a problem exists; (2) if a need for a different approach exists; and (3) where to go for assistance. At the same time a confidence in and acceptance of geotechnical information must be established. Educational seminars and field workshops are important first steps in accomplishing this task, as are field guides and other aids; but if at all possible, a close working relationship with a geotechnician should be established.

Once the need for the slope stability information at a particular site is recognized and a plan developed, the next problem facing the geotechnician is recommending practices that represent cost-effective alternatives. At this point there is a problem. While most geotechnicians have the ability to identify potentially unstable sites, to define the type of problem that is likely to occur with some accuracy, and even to suggest some possible design solutions, there is little factual data on cost-effective design and construction techniques for low-volume forest roads. On some sites there is no easy solution; whatever is done simply costs money. At other sites problems can often be avoided by maintaining a flexible design and construction policy whereby the road is tailored to fit specific slope conditions. For a flexible design and construction policy to be effective, there must be a high level of awareness and flexibility on the part of the construction foreman, project engineer, and specific regulatory agency.

The value of high individual awareness is possibly most evident in the area of road maintenance. After examining large numbers of road-related slope failures in the Pacific Northwest, it is evident that the largest single cause is lack of adequate storm water control. The USDA Forest Service has a storm watch program in many forest districts where critical areas are patrolled to ensure continuing operation of drainage structures. Weyerhaeuser Company initiated a forestry road maintenance program several years ago whereby special budget appropriations are made for maintenance and repair of the nonoperating road net. Both of these programs have greatly reduced the incidence of storm water-induced road failures, but more needs to be done. Road maintenance is a never-ending and costly proposition and, like slope stability, is most beneficial when emphasis is concentrated in sensitve areas.

A LOOK AT THE FUTURE

Up to this point the forest industry has been concerned with locating, designing, and constructing roads to serve as transportation routes for harvest of the old-growth forest. Operating in this environment affords more flexibility in road expenditures than is possible in harvest or thinning operations in the second-growth forest. Although much of the second-growth ready for harvesting now and within the next decade is located on lower elevation lands, many of these sites are highly productive and have their own particular slope stability problems. The primary road systems are usually in place, but many are old railroad routes that often require considerable reconstruction. In some cases construction of additional secondary systems is required for the roads to be compatible with modern raw material handling techniques.

Although the same principles and practices currently used to identify areas of potential slope instability will suffice for second-rotation management, the real challenge is in the development of construction and harvesting technology compatible with economic and environmental constraints, and the effective implementation of this technology in the field.

There is, and will continue to be, a need for development of site-specific slope stabilty assessment methods that the field engineer can apply during road location and construction. Although present use of such methods usually requires a person with specific training in earth sciences, the methods are not as successful as they might be if applied by the field engineer. It is necessary to continue to work on development of techniques that allow the engineer to assign site-specific indices of relative stability along a proposed road location line.

Research into ways to construct roads on lands of inherent instability in an economically and environmentally effective manner would be welcomed by forest managers. Before more research dollars are committed to new methods we should "dust off" existing technology and if applicable, scale it to the environment of the low-volume road. Whatever technology is developed it must be introduced in a form palatable to the intended user and confidence must be established in its effectiveness. Specific technologies are often introduced to the user via the regulatory process. Experience has shown that technology transmitted by regulation will most likely not be effectively utilized and may, in fact, create skepticism and disbelief in what may be a sound practice. Most important, those who work in applied technology, and especially the inexact geological sciences, must stress personal contact to develop credibility with field and management personnel.

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LANDSLIDE DISASTER ASSESSMENT IN THE WASATCH RANGE

Paul Winkelaar

ABSTRACT: During spring 1983, extensive flooding from snowmelt occurred along the western slopes of the Wasatch Range in Utah causing widespread damage in the major population areas around Salt Lake City. Historically, damaging floods in this locality have occurred during isolated and intense summer thunderstorms. In contrast, the floods of 1983 were caused by wet periods that saturated the soils in autumn 1982 followed by heavy winter snow, a prolonged cold spring and sudden high temperatures in May 1983 that produced rapid snowmelt. This is a new phenomena.

USDA Forest Service specialists on three separate advisory teams made helicopter reconnaissance flights twice daily for 3 weeks to map slides and mud flows, and to identify current or potential problems for downstream areas. The teams analyzed data from the reconnaissance flights and from ground operations, developed inundation hazard maps of flood plain areas likely to be affected, and transmitted this information daily to county administrators so appropriate measures could be taken to provide for public safety and to minimize property damage.

INTRODUCTION

During spring 1983 extensive flooding from snowmelt occurred along the west side of the Wasatch Range in Utah. Numerous debris flows and debris floods resulted from the many landslides on the steep hill slopes along the canyons, and caused approximately $300 million in damage.

The Forest Supervisor of the Wasatch-Cache National Forest, Salt Lake City, mobilized technical specialists in three separate teams to provide assistance to local governments and officials in Davis, Utah, and Salt Lake counties, Utah, and in Uinta County, Wyoming. The role of the Davis County team is explored in this paper. The area discussed is the flood area along the Wasatch Range between Mill Creek Canyon and Hobbs Canyon (fig. 1). The towns affected were Layton, Fruit Heights, Kaysville, Farmington, Bountiful, Woods Cross, North Salt Lake, and Centerville.

Approximately 100 landslides that occurred in 22 canyons were monitored and mapped during the two helicopter flights per day between May 29 and June 16, 1983. During the summer months following the floods many landslides were checked and soils examined in the field in an on-going soil survey of the area.

HISTORY OF FLOODING IN DAVIS COUNTY

Davis County pioneers began to establish homes and farms along the steep mountains of the Wasatch Range in 1847. After years of

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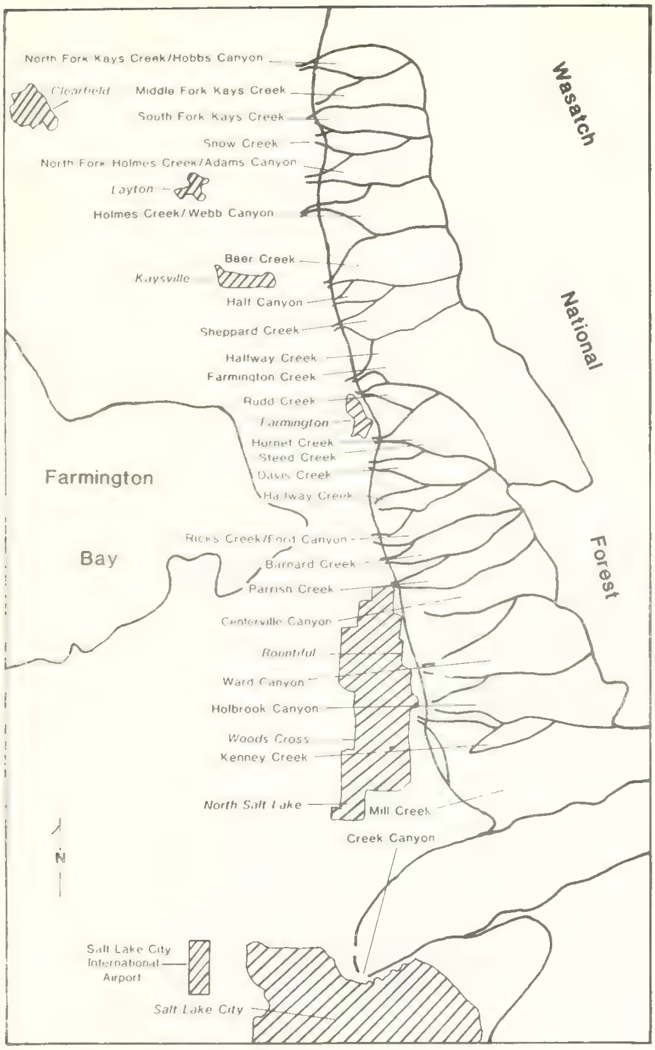

Figure 1.—Planimetric map of the western edge of the Wasatch Range, Utah, between Mills Creek Canyon and Hobbs Canyon showing the area subject to flooding in spring 1983 (Federal Emergency Management Agency, 1983).

overgrazing and frequent fires, the upper watersheds were devoid of vegetation and rains from intense summer thunderstorms produced repeated floods at the canyon mouths. Major floods occurred in 1878, 1901, and 1906, and became more intense and damaging in 1912, 1918, 1923, and 1930.

A flood control commission was established after 1930. This appointed commission recommended a program of increased fire protection, restricted grazing, contour trenching, and reseeding and planting to restore the surface cover in the watersheds. Debris basins were designed to trap sediment from the canyons. As the vegetative cover reestablished, the runnoff from intense summer storms became less damaging, and housing developments replaced fruit orchards and farms at the canyon mouths.

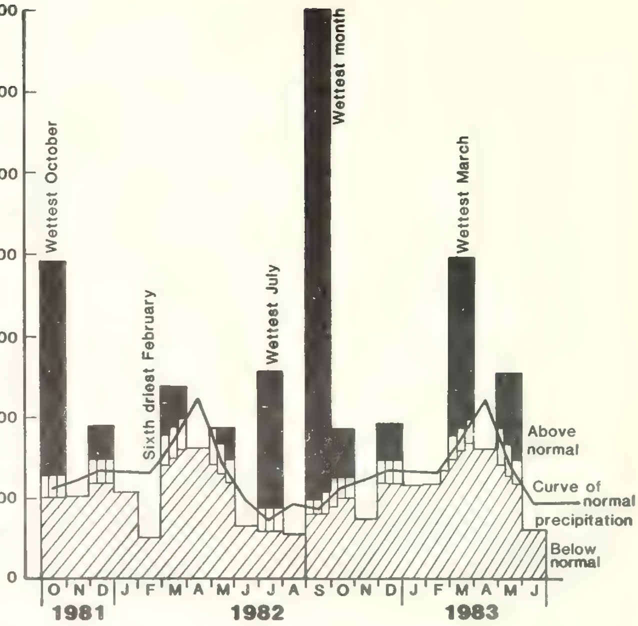

Figure 2.—Monthly precipitation record from the Salt Lake City International Airport for the period of October 1981 through June 1983. The 30-year normal precipitation curve is shown by the solid line. Note that for the 21-month period, four monthly precipitation records are set, October 1981, July 1982, September 1982, and March 1983 (National Weather Service, 1983).

RECENT EVENTS

The mudflows and debris floods in Davis County in spring 1983 were very different from the events of the 1920's and 1930's. The early events were caused by human activities at high elevations in the upper portion of watersheds. The spring 1983 flooding was a natural event and occurred on low to mid elevations within the watersheds. The contour trenches at the upper elevations continue to protect the communities along the range from the intense summer thunderstorms.

As a result of the spring 1983 flooding, there has been a significant change in the Forest Service role in managing the Davis County watersheds. In the past 40 years efforts have focused on fire suppression, maintenance of contour trenches, and the protection of the watersheds from grazing. In spring 1983, Forest Service specialists were directed by the Forest Supervisor to assist the Davis County Emergency Services. Daily flights were made of the watersheds in a Forest Service helicopter to monitor and identify new landslide activity and to evaluate hazards. The Forest Service also provided technical information to the Federal Emergency Management Agency for their assessment of future mudflow and flood risk potential. This information will continue to be made available to Davis County as it is needed to protect life and property.

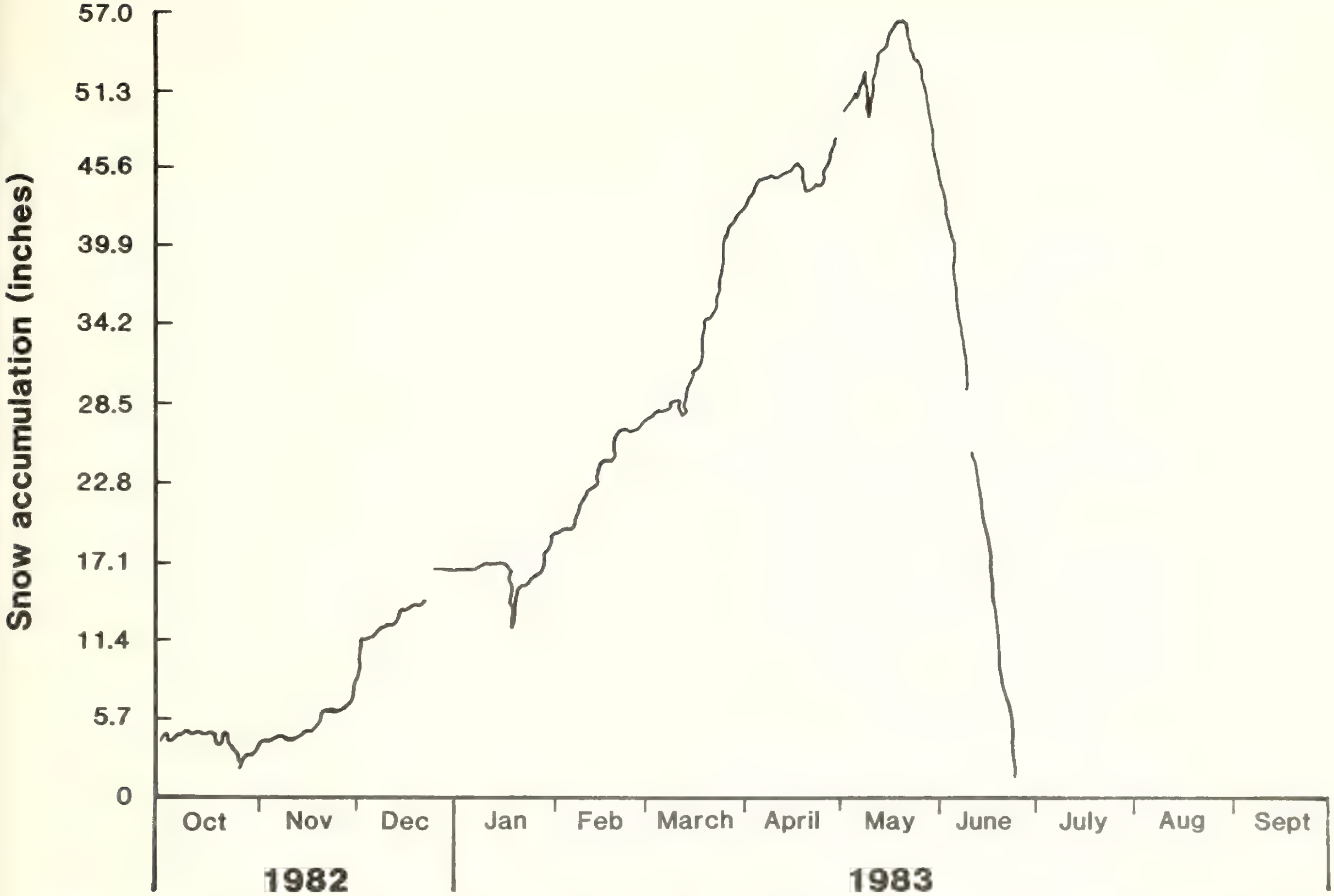

Figure 3.—Snow accumulation (water equivalent) at the 8,010-foot elevation in Farmington Canyon, Utah, for the 1983 water year (October 1982 to September 1983). Snow continued to fall through the middle of May, peaking on May 19. This is about 1 1/2 months past the normal peak around April 1 (National Weather Service, 1983).

CONDITIONS LEADING TO THE 1983 DISASTER

The severely unstable soil conditions that prevailed along the Wasatch Range from April through June 1983 began in the water year of 1981-1982.[1] It was the wettest year in over 100 years of record in the Salt Lake Valley (Kaliser, 1983; National Weather Service 1983). Annual precipitation was 10 inches above the 30-year normal. For the 21-month period from October 1981 through June 1983, four monthly precipitation records were set: October 1981, July 1982, September 1982, and March 1983 (fig. 2). The one "century storm" that saturated the soils in autumn fell in the later part of September with rainfall ranging from 11 to 13 inches across the Wasatch Range.

The heavy winter snow of 1982-1983 compounded the problem (fig. 3). The snow continued to fall through the middle of May, in fact peaking at this time. This is about 1-1/2 months later than the normal snowfall peak around April 1. A 20-inch snowfall at Alta, Utah on May 19, 1983, elevated the winter snowfall there to a record 805 inches. It was estimated that there was from 40 to 60 inches of water in the snowpack at about the 8,000-foot elevation.

Between May 27 and May 31, temperatures rose into the 80's and lower 90's(°F). This accelerated the rapid runoff from the snowpack. During the week following the Memorial Day weekend, moderate or heavy thunderstorms aggravated the already serious situation.

MAJOR EVENTS IN THE WASATCH RANGE IN DAVIS COUNTY

May 25, 1983	Centerville Creek spilled over its banks.
May 26, 1983	Sudden hot weather initiated the crisis. Flooding began in Salt Lake City. Slides occurred in Big Cottonwood Canyon.
May 27, 1983	Mill Creek flooded in West Bountiful along the Union Pacific

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[1] A water year begins in October.

	tracks and on 5th Street South. Flood waters cut a hole 60 feet wide and 20 feet deep in Bountiful's Lakeview Drive. Nursing homes evacuated as water broke through dikes and crashed against buildings.
May 28, 1983	Barnard and Ricks Creeks flooded, and damaged homes in Centerville. Water from Barton Creek finished washing out Lakeview Drive and broke sewer lines in Bountiful. Homes and businesses along Stone Creek were also flooded.
May 29, 1983	A mudslide down Bigler Creek took out 30 yards of road in Farmington Canyon.
May 30, 1983	A 20-foot-high mudflow descended on Farmington. Mud covered a 9-block area and 250 people were evacuated. Twelve homes were damaged and six destroyed. Lagoon resort was forced to close by the threat of the mudslide.
May 31, 1983	The Interstate-15 frontage road west of Centerville was forced to close. Water from Rick's Creek in Centerville caused a pond to break out of its banks, sending a flood of water through the Willow Creek subdivision. Water and mud cascaded down Stone, Barton, and Mill Creeks in Bountiful inundating 250 homes with a pudding-like mud. Three homes were destroyed, 11 had major damage and 450 people were evacuated. A second mudslide out of Rudd Canyon in Farmington demolished some homes and damaged others forcing the evacuation of many residents. Stone Creek in Bountiful swept 1,800 gallons of tranformer oil containing toxic PCB into a basement.
June 1, 1983	A 25-foot wall of water rushed out of Stone Creek forcing the evacuation of hundreds of families. Several families in Fruit Heights area were forced to evacuate because of a slide threat.
June 7, 1983	A large slide slowly started moving down Coldwater Creek Canyon into North Ogden forcing evacuations.

LANDSLIDE CHARACTERISTICS

An oblique sketch of a typical debris flow from a steep canyon wall in the Wasatch Range is shown in figure 4. The geology of the Wasatch Range in Davis County is dominated by the Farmington complex. The gneiss and schist that constitute most of this unit have been extensively weathered resulting in coarse-grained granular soils that include zones of silt and clay. Most of the landslides that were mobilized as debris flows failed at the base of the coarse- and medium-textured soil at the rock interface.

Many slides also showed positive pore pressure zones in their headwalls which was caused by greatly increased amounts of groundwater from rapid snowmelt. After failure, excess water continued to flow freely from the headwalls and formed surface streams, a phenomenon that could be readily observed during the reconnaissance flights. In summer many landslide headwalls were still seeping in these positive pore pressure zones.

Following initial failure, many landslide zones developed cracks above the headwalls, and many detached soil masses consequently remain on the slope. These areas, in particular, were monitored and checked daily. Such areas could, if mobilized, produce debris slides and jams and cause the dangerous, damaging surges of debris flows or debris floods in the stream channels.

Most of the landslides developed on north- and south-facing slopes, with a few on upper west-facing slopes. The canyon terrain is very steep with slope ranges between 60 to 90 percent.

The vegetation is mainly stands of maple, scrub oak, and aspen with open areas of grass-sage-shrubs on south-facing slopes. Dense stands of Douglas-fir and small stands of aspen are on the north-facing slopes. Most slides occurred in the wetter aspen stands.

The landscape is one of an extended prominant mountain ridge that trends in a north-south direction with numerous, steeply incised canyons running east and west. The elevation on the ridge tops ranges from 10,000 to 11,000 feet, with the lowest elevations at the mouth of canyons between 5,000 and 6,000 feet. Many subdivisions and housing developments have been built on the old alluvial debris fans that developed over time below the canyon mouths. It is in these areas that much of the damage to homes and property occurred.

RESOURCE TECHNICAL TEAM ACTIONS

In response to this urban flooding and landslide damage, an interagency resource technical advisory team was formulated by the State of Utah, Utah Geological and Mineral Agency, Davis County commissioners, and the Wasatch-Cache National Forest supervisor. In Davis County, the resource technical advisory team consisted of four Forest Service employees--two regional office geotechnical people, one regional office hydrologist, and one forest soil scientist; one state geologist; the Davis County engineer; and the county water quality specialist. The state geologist headed the team. The team operated out of the Emergency Operations Center located in the Davis County library in Farmington. The situation called for aerial reconnaissance of the

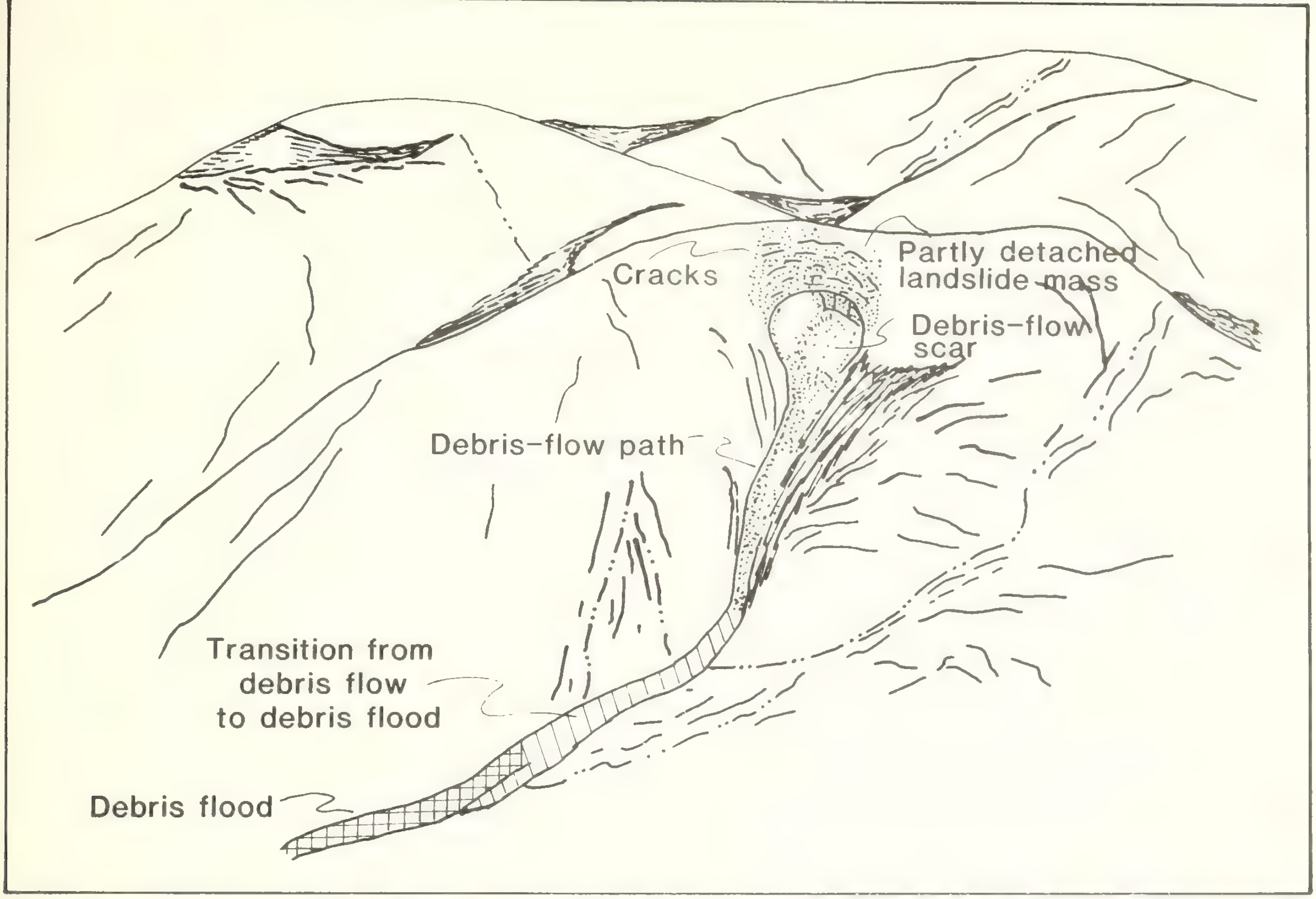
Partly detached landslide mass
Cracks
Debris-flow scar
Debris-flow path
Transition from debris flow to debris flood
Debris flood

Figure 4.—Oblique sketch of a typical debris flow from a canyon wall showing the transition from a debris flow to a debris flood in the main stream channel.

canyons by helicopter twice a day. Each day the forest engineer, acting as the flood boss, received a comprehensive report of the flood and landslide conditions as observed during the flights. A large room was used solely by the committee members with maps (scaled at 1 inch to 200 feet) hung on the walls. These maps, provided by the County Planning Department, became the base maps for the rapid preparation of potential inundation or damage area maps by the county engineer and forest soil scientist. The maps outlined first- and second-alert zones where flooding could be expected. As quickly as these maps could be completed, they were dispatched to the respective mayors. Priority of preparation was assigned based on the canyon hazard ratings. These hazard ratings were determined for all Davis County drainages and were based on observations made during aerial reconnaissance. To minimize property damage, the information obtained during these reconnaissance flights was transmitted daily to the county administration so appropriate planning and action could be implemented; i.e., where to build dikes, sand bag walls, monitor mud or debris flows, place equipment and personnel, and construct diversion channels.

This technical team functioned for a period of 3 weeks. Its final action was the release on June 21 of a canyon rating list that apprised local governments of the relative degree of hazard existent in the canyons at the time. Local officials were also warned that high-intensity summer storms were capable of creating debris flows in these canyons because unstable slopes with partly detached soils existed.

The Davis County Technical Committee may well serve as a model for dealing with similar crises in the future.

MONITORING TECHNIQUES

Two techniques were used by the technical specialists to map landslides.

1. Preliminary reconnaissance mapping was done on 1:24,000, black and white aerial photographs taken in 1980. Erasable grease pencils were used to draw maps on the aerial photos. These aerial photos were matched and joined with all the drainages outlined in blue; the names of the canyons and streams were included .

2. Mapping was also done from a helicopter with all features transferred directly to 1:40,000 water rights contour maps. ~~B~~ecause the maps clearly and accurately show the elevations, they

became an excellent tool to verify location in the canyon by checking positions with the altimeter in the helicopter. Because the forest is completely mapped at this scale, this will be the preferred method for the future. Another advantage to this approach is that personnel not familiar with aerial photo interpretation can easily use these maps.

When flying the reconnaissance flights, careful observation was essential. It was particularily important that accurate notes be kept on all features that might indicate existing or potential risk of debris flows and floods reaching the canyon mouths. These included:

1. Presence, growth, and appearance of ground displacement cracks. An accurate count was essential to judge additional movement that could create mudflows.

2. Amount of water entering the slides either through positive pore pressure zones or from interrupted stream channels emptying the snowmelt waters in the slide.

3. Color of the floodwater. Muddy water often indicated the presence of debris jams.

4. Sudden changes in the depth or amount of floodwater in the channel.

5. Size and amount of partly detached landslides perched on the steep hills and canyon sides. These partly detached masses appeared to be the most likely sources for debris flows in the future.

6. Presence of debris jams in the stream channels. Jams were usually caused by dislodged trees entering the stream channel or by landslide deposits occupying the canyon bottom.

7. It was often observed that the landslide activity followed the snowline by approximately 2 days; that is, the saturated soils would crack and slide 2 days after the snowline retreated to a higher elevation. Snowlines were mapped at intervals when it became apparent that sliding activity would increase. In severe cases, cracks would be apparent in the snow.

ADDITIONAL DATA NEEDS

The following data needs were identified by the Federal Emergency Management Agency team (FEMA) based on the data collected on the potential for debris floods along the Wasatch Range (Federal Emergency Management Agency, 1983; Wieczorek and others, 1983). The team consisted of four geologists from the U.S. Geological Survey, Menlo Park, California and an engineer from the Los Angeles County Flood Control District, Los Angeles, California. These professionals had considerable experience in evaluating flood potentials based on their work in Southern California, an area that is plagued by landslides and flooding.

1. Relationships between rainfall (or snowmelt), ground-water levels, and landslide movement. Such relationships would permit prediction of timing of debris flows. Real-time prediction and warnings could then be made based on telemetered information on rainfall, ground-water level or ground movement.

2. Stability of the partly detached landslides. Are these masses in fact significantly less stable than nearby hillslopes, and how long will they remain so? These questions should be approached through detailed, site-specific studies including stability analyses of the landslides.

3. The process of transformation from landslide to debris flow. Understanding developed through such study could help evaluate the potential for debris flow of the partly detached landslides.

4. Incorporation of channel materials by debris flow. Possible variations in materials available for incorporation is one of the major uncertainties of our analysis.

5. The transition from debris flow to debris flood. Understanding of this transition would permit more accurate prediction of the nature of flow from canyon mouths.

6. Factors that control debris-flow runout. Understanding of runout would help in predicting those areas likely to be affected beyond canyon mouths.

7. Recurrence of debris floods and debris flows at canyon mouths. Systematic field investigation and dating of deposits would help define the potential frequency of events from each canyon.

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APPLICATIONS OF GEOTECHNICAL DATA TO FOREST MANAGEMENT

Tom Reilly and Bill Powell

ABSTRACT: Prior to 1980, geotechnical and geologic data were gathered on a project basis in the Gifford Pinchot National Forest in southern Washington. After conducting a study of costs and related benefits, the Forest management personnel approved on a Forest-wide basis the development of Geologic Resource Data (GRD) by the geotechnical group. The initial data collection was completed in 1982 at a total cost of approximately $200,000. This investment has already been recouped in cost savings associated with rock resource management and has provided the Forest with a more effective approach to stability-associated problems in planning and project implementation. As part of the GRD, Geological Resources and Condition Maps (GRC) were constructed to assist management with Geotechnical information. Generally, all existing landslides were classified into seven different categories, based on process of failure, and mapped along with engineering and geological information relating to existing soil and rock conditions. The GRC does not always provide a final answer to Forest and timber sale planners, but will provide information to make decisions when further geotechnical analysis or investigation might be economically warranted. The development of Geologic Resource Data (GRD) and Geologic Resources and Conditions (GRC) maps provide the Forest geotechnical group with a tool to promote involvement in the planning process at the earliest stages. With this involvement the geotechnical personnel can establish the priority of the various stability problems on a Forest-wide basis and schedule field investigations in a more systematic manner. The GRD was designed to be updated, as project work and more detailed stability studies are completed, each update improving the accuracy and reliability of information.

INTRODUCTION

Starting in 1980 the Gifford Pinchot National Forest geotechnical group embarked upon a geologic data collecting process referred to as the Geologic Resource Data (GRD). Initially, information was gathered over a 2-year period on a Forest-wide basis. Most of the data collection was completed during the 1981 field season. In 1982, primarily for support to transportation planning, the GRD data was analyzed and portrayed on a single map—Geologic Resources and Conditions (GRC). The data base was set up to have application and benefits to USDA Forest Service programs, and the information has been tested on land management planning, area and timber sale planning, and project site investigations. The results have greatly exceeded original expectations; and because the resource data was meant to be continually

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updated, the information will be progressively more effective in the future.

The Gifford Pinchot National Forest is not considered the most unstable Forest in the Pacific Northwest Region, but the type of failures, the geologic conditions, and frequency of failures vary considerably throughout the Forest. The GRD was designed to have many uses, and one use of primary importance is application for slope stability assessment. This report will primarily address slope stability; but the reader should be aware that, the system was predicated on many other technical applications and has wide application at the Forest and project levels.

DEFINING THE NEED AND SUPPORT TO DEVELOP THE RESOURCE DATA

Since the Gifford Pinchot Geotechnical group leadership was centrally organized in 1975, the need for collecting and interpreting geologic data has been increasingly evident. Some of the main reasons are:

1. Simplified, geologic conditions have consistencies and inconsistencies that can be measured and projected over an area between locations. This information can be related to engineering characteristics including slope stability. This type of analysis was occasionally used by the Forest geotechnical group on smaller, defined areas. It appeared that if similar information were available on a Forest-wide basis, there would be more precise information on which to make stability predictions with limited additional field work at the planning stage.

2. The Forest had geotechnical specialists with many years of experience working in defined areas. It would take years for a new person to gain this field experience. A data base would be a method to display, store, and update engineering geology information on a continual basis and provide new personnel with information in an understandable form.

3. Prior to 1980, project and area transportation planning was a function of the Ranger District and geotechnical services were provided by the engineering staff. Geotechnical personnel worked on a request basis and program effectiveness varied, depending on the individuals involved. Some planners requested assistance on every project and some planners did not request any assistance. The geotechnical group not only felt that a data base would improve the recommendations and increase the visibility of useful available data, but would provide a method of establishing the priority of the stability work Forest-wide. The geotechnical group would also have backup information to support their decisions.

In spite of the obvious benefits that could be derived from a GRD, there was reluctance by management to support the expenditure. The estimated initial cost was $200,000 over a 2-year period, and the program would set a precedent of establishing a geologic data base over an entire National Forest. The Forest already had a soils resource inventory, so the need for a geologic data base was not obvious. A considerable amount of time was spent discussing the potential dollar savings and value of a GRD before management would approved the expenditure. In 1980 the Forest was forming a interdisciplinary team to complete the Forest Land Management Plan to the standards of the National Forest Management Act. The GRD information could be used effectively in completing this plan. Finally, just prior to the 1980 field season, the geotechnical group obtained approval to proceed with gathering the field data.

DEVELOPMENT OF THE DATA BASE

Prior to the GRD program, geologic inventory and analysis were carried out on a project basis, and project files were the only means of "storing" geologic data. There was no long-term system to store and retrieve geologic data that could prove useful to planning efforts or future project work, and there was little opportunity to break out of the "project mode."

The formulation of the GRD program was envisioned as an opportunity to develop a system for providing data for National Forest planning. The system could be structured to serve as a repository of all geologic data and should prove invaluable to second-order plans and future project work. With a long-term goal in mind, considerable thought was given not only to immediate planning needs but long-term usefulness of the data. The GRD system and method were developed to be uniform throughout the Forest; to be sustained and enhanced by additions of new data; to act as the starting point or base for future geologic investigations; and to be the repository for newly acquired geologic data. The basic effort was to gather technical data and to distill it to be both understandable and usable by nontechnical planners and Forest managers. Yet, the data also had to be technically sound to make engineering and other resource recommendations.

Considerable teamwork and discussion were needed to reach consensus on the type of data to be gathered. Short- and long-term usefulness of the data and potential applications had to be considered and technically sound but understandable terminology, and graphic display symbols had to be devised. The Forest Geologist, with assistance from engineering zone geotechnical personnel, formulated guidelines for the types and levels of data to be gathered. Map and file systems were developed to ensure uniformity. Data were gathered for defined land areas called Total Resource Information (TRI) compartments. There are 254 of these land areas, each averaging approximately 6,500 acres, comprising the Forest land base. The TRI system consists of subsystems of layered resource displays and data files for each TRI compartment map. There are currently 13 other resource inventories (timber, wildlife, transportation, etc.) mapped and displayed in the TRI system. Most field information was obtained by driving Forest roads; driving had to be supplemented in some areas by walking. Temporary employees were hired to gather the data under the immediate supervision of zone geotechnical personnel, with overall direction and review by the Forest geologist. Figure 1 outlines the inventory process.

The GRD was founded on the principle that data gathered must have application and benefit to Forest Service programs. It was set up to gather and display data at a general level of resolution for long-range plans, and to be ground reviewed and further classified at a more intensive level for area and project planning. The process was not envisioned to result in a classic academic geologic map filled with jargon and difficult to interpret. Materials were classified and assessed, based on physical characteristics and response to modification by management activities. Slopes were evaluated not merely to classify as stable or unstable, but features were classified by type of process or mechanism of failure, which allows future prediction of response to modification. Conditions existing on unstable slopes have been compared to those conditions on similar slopes where failure has not yet occurred in order to further understand the mechanism of failure and predict failure potential.

To the engineering geologist, all landslides are not alike. Each landslide responds differently to management activities depending on physical conditions and processes. Many managers wondered why such a data base was necessary in light of the existing Soil Resource Inventory, but the soil inventory was not as comprehensive in evaluating slope stability and lacked sufficient detail for making quantitative predictions and recommendations.

Because geologists in the Forest Service are involved in both surface and subsurface resources, conditions and processes, the data was displayed in two layers. Accordingly, the GRD is structured by TRI compartments in two overlays: rock and surficial materials. Figure 2 outlines the content of the overlays.

The entire Forest has been mapped and bedrock units designated. Bedrock units are defined as rock masses of similar origin (igneous extrusive and intrusive, pyroclastic, sedimentary, and metamorphic) mapped at a scale of 4 inches to 1 mile and are distinguished by a numerical system. The primary basis for bedrock unit designation is rock origin, but all bedrock units have also been classified according to the Unified Rock Classification System. This system (developed by Doug Williamson, engineering geologist, Willamette National Forest) provides a reliable method of assessing rock mass engineering characteristics and physical parameters necessary to predict rock quality, stability, and response to management activity.

1. OFFICE PREPARATION - Compile onto base map

AIR PHOTO INTERPRETATION
SOIL RESOURCE INVENTORY (SRI) REVIEW
PROJECT FILE REVIEW
MATERIALS SOURCE FILE REVIEW (quarry files)
PUBLISHED GEOLOGIC LITERATURE REVIEW

2. FIELD WORK - Verify accumulated data - "ground truth"

ESTABLISH DATA POINTS AND MILEPOST LOG
MEASURE AND CLASSIFY MATERIALS AND STABILITY FEATURES
PHOTOGRAPH AND SAMPLE
ESTABLISH BEDROCK UNITS
VERIFY BOUNDARIES AND CONTACTS
REVIEW MATERIALS SOURCE DATA AT THE SITE

3. COMPILATION

ORGANIZE AND SUMMARIZE TRI COMPARTMENT DATA PRIOR TO OFFICE PREPARATION FOR NEXT COMPARTMENT

Figure1--The Geologic Resource Data (GRD) collection process.

1. ROCK OVERLAY

- BEDROCK UNITS
- MATERIALS SOURCES BY CATEGORY
- BEDROCK STRUCTURE
- AREAS OF ROCK OUTCROP AND TALUS
- GEOLOGIC POINTS OF INTEREST

2. SURFICIAL OVERLAY

- MASS MOVEMENT FEATURES BY CATEGORY
- AREAS OF MAPPABLE GROUNDWATER OCCURRENCE
- SIGNIFICANT MAPPABLE TRANSPORTED SOIL DEPOSITS

Figure 2--Content of Geologic Resource Data (GRD) overlays.

Mass movement is a sensitive natural process that human activities can accelerate or decelerate; with a potential for adverse effects to the environment. Activities such as timber harvest, road construction, or facility placement can initiate or accelerate mass movement, often with catastrophic results.

Mass movement can be decelerated through intervention, but often this requires costly engineering techniques. Confirmed or suspected areas of unstable ground may or may not tolerate management activity depending on specific site conditions. The GRD displays known and inferred areas of unstable slopes throughout the National Forest as a first approximation of potential problems. This display serves as the basis for planning future fieldwork to verify the nature of the problem and to recommend specific mitigation measures. Based on the information gathered, accurate predictions can be made on the potential impacts from road construction and timber harvest using predictive computer modeling techniques. Results of predictive modeling of slope stability is only as accurate as the data used to define the physical conditions of the site, such as soil and rock engineering characteristics. Without an adequate data base, the use of these techniques is limited.

Seven categories of mass movement or instability have been mapped and displayed in the GRD, each category distinguishable by Roman numerals. These categories were developed to differentiate process or mechanism of failure and are described in figure 3. The areal extent of the feature is mapped and displayed, and the feature is classified as to mechanism of failure. When reviewed in the field, additional geologic and engineering information is gathered on soil, rock, and groundwater conditions for future application. Aside from adverse resource impacts such as water quality degradation, some slope failures have long-term impacts on site productivity.

DEVELOPING MAPS OF GEOLOGIC RESOURCES AND CONDITIONS

After the GRD was completed, the technical data needed to be distilled and synthesized to provide a user-friendly, simply structured, yet technically sound, end product for use by nontechnical planners for National Forest and area planning. This led to the development of the Geologic Resource and Conditions Maps (GRC).

The Geologic Resources and Conditions Maps are built through analysis and synthesis of the Geologic Resource Data of rock and surficial layers. Geologic resources and conditions are defined consistent with national and Forest criteria, and are shown in figure 4. The relationship between GRD, GRC, and subsequent field work is displayed in figure 5.

I. SLIDES
- ROTATIONAL AND/OR TRANSLATIONAL FAILURES
- SOIL/BEDROCK OR BOTH TYPES OF MATERIAL
- ACTIVE OR PAST ACTIVE (CURRENTLY STABLE)

II. FLOWS
- DEBRIS SLIDES, DEBRIS FLOWS, DEBRIS AVALANCHE
- TERM APPLIED DEPENDS ON WATER CONTENT, MOBILITY, AND CHARACTER OF MOVEMENT
- SOIL PARTLY OR COMPLETELY DECOMPOSED BEDROCK OR COMBINATION

III. ROCKFALL/TALUS
- TOPPLING AND FALLING OF FAILURES IN ROCK

IV. AVALANCHE
- SEASONAL AREAS OF SNOW/ICE MOVEMENT
- OFTEN ACCOMPANIED BY ROCK, SOIL, AND ORGANIC DEBRIS

V. SIDECAST FAILURE (INITIATED BY ROAD CONSTRUCTION)
- CONSTRUCTION WASTE END DUMPED OR LOOSELY PLACED ON SLOPES EXCEEDING 55 PERCENT WITH RESULTANT FAILURE

VI. FILL FAILURE (ROAD FILL)
- FILL PLACED ON SLOPES LESS THAN 55 PERCENT WITH RESULTANT FAILURE

VII. CUTSLOPE FAILURE (ORIGINATING AT A ROAD)
- CUTSLOPES EXHIBITING EXCESSIVE RAVEL OR MASS FAILURE

Figure 3--Soil mass movement categories mapped and displayed in the Geologic Resource Data (GRD) process.

GEOLOGIC RESOURCES
- EARTH CONSTRUCTION MATERIALS
- GROUNDWATER
- UNDERGROUND SPACE (I.E., CAVES)
- GEOLOGIC POINTS OF INTEREST (EXAMPLES OF UNIQUE OR SPECTACULAR FEATURES DEPICTING GEOLOGIC PROCESSES OR PHENOMENA OF THE EARTH'S EVOLUTION; I.E., VOLCANIC OR GLACIAL LANDFORMS).

GEOLOGIC CONDITIONS

FEATURES OR PROCESSES THAT AFFECT THE SAFETY, COST, OR FEASIBILITY OF RESOURCE MANAGEMENT ACTIVITIES AND DEVELOPMENT
- ROCK OUTCROP AND TALUS
- MASS MOVEMENT (INCLUDING ROCKFALL AND AVALANCHE AREAS)
- MAPPABLE WET AREAS (SPRINGS AND POORLY DRAINED GROUND)

NOTE: MANY OF THESE GEOLOGIC CONDITIONS ARE SOMETIMES REFERRED TO AS "GEOLOGIC HAZARDS." THIS HAS BEEN AVOIDED BECAUSE OF THEIR SUBJECTIVE NATURE, WHICH IMPLIES HAZARDS TO PEOPLE OR STRUCTURES. THE CONDITIONS COULD POSE HAZARDS IF NOT AVOIDED, BUT ARE NOT HAZARDS IN THEMSELVES.

Figure 4--Criteria used to define units on Geologic Resources and Conditions (GRC) maps.

Each map delineates Geologic Materials Units (GMU), each distinguished by symbol, which consist of deep soil deposits (greater than 15 feet) residual soil deposits, transported soil deposits and bedrock. Delineation of a soil GMU vs. a rock GMU is dependent upon relative depth of soil--the dominant geologic condition of that particular area. For example, if the soil depth is estimated at 20 feet, the physical properties of the soil and the surficial processes are the dominant geologic condition for that particular area, and the underlying bedrock is subordinant in importance. If by chance bedrock information is required for a soil-based GMU, it can be obtained from GRD rock overlays. In most instances, the GMU boundaries correspond with bedrock unit boundaries. The GMU is used as the framework to provide interpretations as to geologic resources and conditions (such as slope stability) for the discrete Forest land area. The specific content of GRC maps is described in figure 6. Figure 7 is an example of the typical information contained in a GRC map margin, and figure 8 displays the standard map legend.

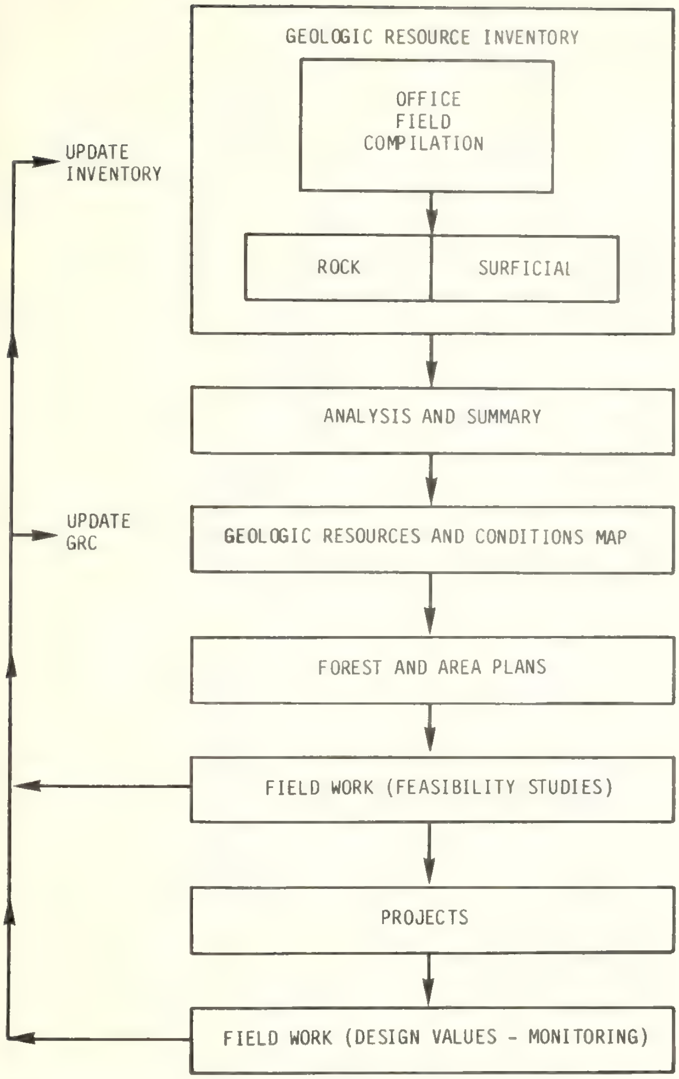
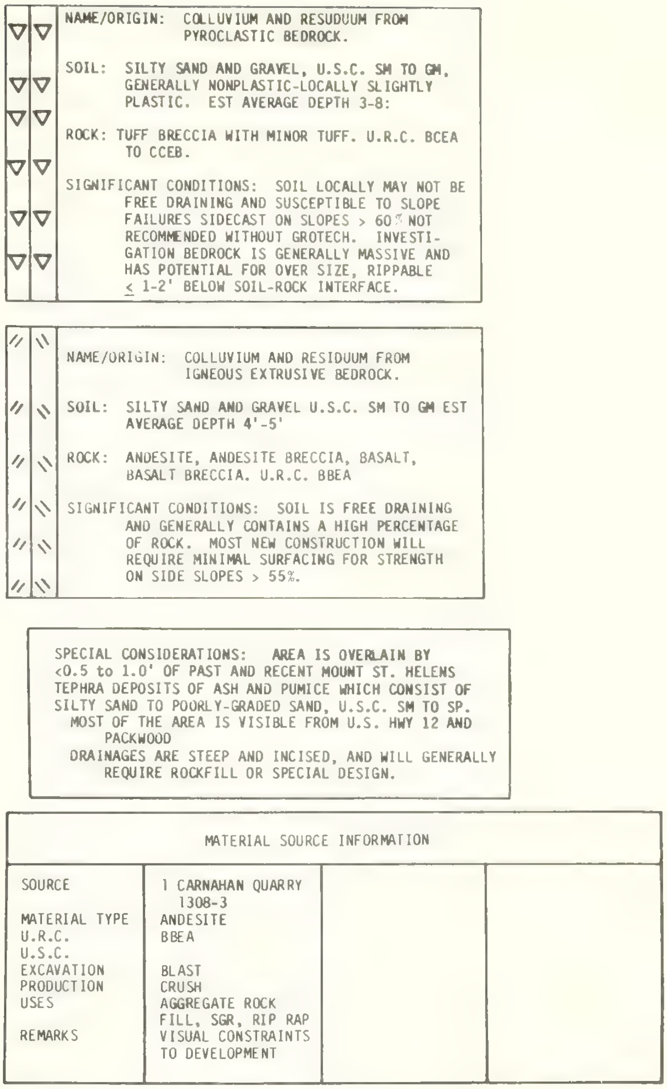

GEOLOGIC RESOURCE INVENTORY
OFFICE
FIELD
COMPILATION
ROCK
SURFICIAL
UPDATE INVENTORY
ANALYSIS AND SUMMARY
UPDATE GRC
GEOLOGIC RESOURCES AND CONDITIONS MAP
FOREST AND AREA PLANS
FIELD WORK (FEASIBILITY STUDIES)
PROJECTS
FIELD WORK (DESIGN VALUES - MONITORING)

Figure 5--Relationship between GRD, GRC and project planning and design.

- TOPOGRAPHIC BASE MAP 4" = 1 MILE SCALE (TRI COMPARTMENTS)
- GEOLOGIC MATERIALS UNITS (BASED ON RESIDUAL [PARTLY OR COMPLETELY DECOMPOSED ROCK] OR TRANSPORTED SOIL DEPOSITS, OR BEDROCK UNIT BOUNDARIES) AND DESCRIPTION
- GEOLOGIC RESOURCES AND CONDITIONS BY SYMBOL
- MATERIALS SOURCE SUMMARY TABLE
- SPECIAL CONSIDERATIONS (POTENTIAL GEOLOGIC CONSTRAINTS OR OPPORTUNITIES) FOR EACH GMU
- TRI COMPARTMENT SUMMARY
  - AREA GEOLOGICAL SETTING AND ORIGIN
  - SOIL/ROCK MATERIALS PROPERTIES
  - SLOPE STABILITY FACTORS
  - GEOLOGIC RESOURCE INFORMATION
  - SPECIAL CONSIDERATIONS FOR THE OVERALL COMPARTMENT

Figure 6--Specific content of Geologic Resources and Conditions (GRC) maps.



NAME/ORIGIN: COLLUVIUM AND RESUDUUM FROM PYROCLASTIC BEDROCK.

SOIL: SILTY SAND AND GRAVEL, U.S.C. SM TO GM, GENERALLY NONPLASTIC-LOCALLY SLIGHTLY PLASTIC. EST AVERAGE DEPTH 3-8:

ROCK: TUFF BRECCIA WITH MINOR TUFF. U.R.C. BCEA TO CCEB.

SIGNIFICANT CONDITIONS: SOIL LOCALLY MAY NOT BE FREE DRAINING AND SUSCEPTIBLE TO SLOPE FAILURES SIDECAST ON SLOPES > 60% NOT RECOMMENDED WITHOUT GROTECH. INVESTIGATION BEDROCK IS GENERALLY MASSIVE AND HAS POTENTIAL FOR OVER SIZE, RIPPABLE ≤ 1-2' BELOW SOIL-ROCK INTERFACE.

NAME/ORIGIN: COLLUVIUM AND RESIDUUM FROM IGNEOUS EXTRUSIVE BEDROCK.

SOIL: SILTY SAND AND GRAVEL U.S.C. SM TO GM EST AVERAGE DEPTH 4'-5'

ROCK: ANDESITE, ANDESITE BRECCIA, BASALT, BASALT BRECCIA. U.R.C. BBEA

SIGNIFICANT CONDITIONS: SOIL IS FREE DRAINING AND GENERALLY CONTAINS A HIGH PERCENTAGE OF ROCK. MOST NEW CONSTRUCTION WILL REQUIRE MINIMAL SURFACING FOR STRENGTH ON SIDE SLOPES > 55%.

SPECIAL CONSIDERATIONS: AREA IS OVERLAIN BY <0.5 to 1.0' OF PAST AND RECENT MOUNT ST. HELENS TEPHRA DEPOSITS OF ASH AND PUMICE WHICH CONSIST OF SILTY SAND TO POORLY-GRADED SAND, U.S.C. SM TO SP.
MOST OF THE AREA IS VISIBLE FROM U.S. HWY 12 AND PACKWOOD
DRAINAGES ARE STEEP AND INCISED, AND WILL GENERALLY REQUIRE ROCKFILL OR SPECIAL DESIGN.

MATERIAL SOURCE INFORMATION			
SOURCE	1 CARNAHAN QUARRY 1308-3		
MATERIAL TYPE	ANDESITE		
U.R.C.	BBEA		
U.S.C.			
EXCAVATION	BLAST		
PRODUCTION	CRUSH		
USES	AGGREGATE ROCK FILL, SGR, RIP RAP		
REMARKS	VISUAL CONSTRAINTS TO DEVELOPMENT		

Figure 7--An example of typical information contained in a GRC map margin.

APPLICATIONS OF GRC MAPS

The GRC maps have many applications to Forest resource management activities. One such application is in the planning and design of timber sales.

The Timber Sale Gate System is a planning process used at the Gifford Pinchot National Forest and developed to systematically gather and evaluate pertinent data that ultimately affects the location and layout of future timber sales. The gate system has six steps, each defining data collection and analysis required prior to moving to the next step in the process. Each gate is of increasing specificity. The gate system serves as the framework to coordinate input by all resource specialities.

Geologic Resources and Conditions Maps display basic geologic reconnaissance-level data that designate geologic factors affecting land

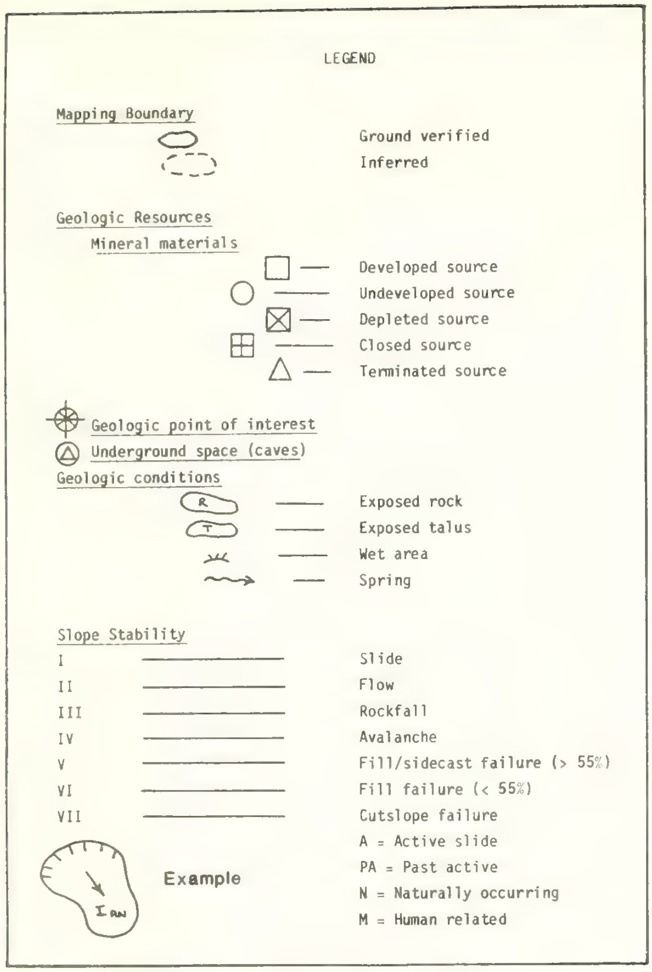


Figure 8--Standard legend used on GRC maps.

allocation, general facility locations, and management alternatives. GRC maps, including the respective TRI compartment summaries properly interpreted by a geology or geotechnical specialist, provide invaluable data for the planner to develop initial land constraints or opportunities. They also supply critical elements to sale implementation which are part of the position statement (gate 1 of the Timber Sale Gate System). This leads to scheduling of field data collection to verify potential problems identified on the GRC before completion of sale area design (gate 2). GRC maps allow for initial gate 1 input, then serve to provide a basis to schedule further classification and quantification of geologic factors as they affect specific facility locations or land use and management decisions necessary for gate 2, sale area design. GRC maps provide an ideal and extremely useful tool to identify concerns regarding slope stability (as well as other geologic factors) at the earliest planning stages (gate 1), to verify in the field the condition during sale area design (gate 2), and to mitigate potential adverse environmental impacts during project design (gate 3). Figure 9 displays the relationship between GRC and the gate system.

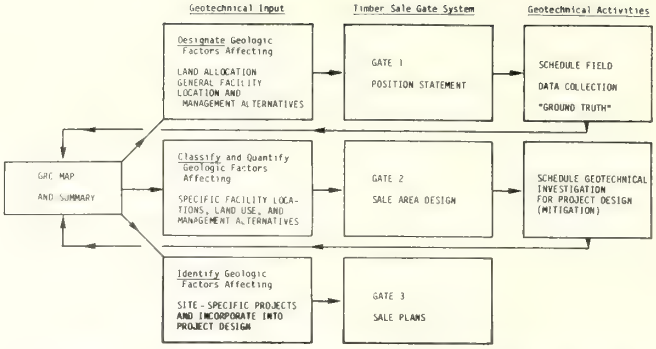

Geotechnical Input
Timber Sale Gate System
Geotechnical Activities
Designate Geologic Factors Affecting
LAND ALLOCATION GENERAL FACILITY LOCATION AND MANAGEMENT ALTERNATIVES
GATE 1
POSITION STATEMENT
SCHEDULE FIELD
DATA COLLECTION
"GROUND TRUTH"
GRC MAP
AND SUMMARY
Classify and Quantify Geologic Factors Affecting
SPECIFIC FACILITY LOCATIONS, LAND USE, AND MANAGEMENT ALTERNATIVES
GATE 2
SALE AREA DESIGN
SCHEDULE GEOTECHNICAL INVESTIGATION FOR PROJECT DESIGN (MITIGATION)
Identify Geologic Factors Affecting
SITE-SPECIFIC PROJECTS AND INCORPORATE INTO PROJECT DESIGN
GATE 3
SALE PLANS

Figure 9--Relationship between GRC maps and the timber sale gate system.

1. Recreation--Geologic resource data (points of interest for interpretive programs; groundwater information for recreation sites)
2. Timber--Geologic materials units probably correlate with site productivity
3. Water and Soil--Forest soil scientists currently utilizing GRC maps in project evaluation; of proving useful for preliminary evaluation of potential hydroelectric permit applications
4. Minerals and Geology--Estimating potential impact from mineral resource evaluation and exploration; common variety mineral materials sources located on GRC maps
5. Lands--Potential use of GRC maps to evaluate relative value of geologic resources in National Forest land considered for sale or exchange.

Figure 10--Potential applications of GRD and GRC data to other resource programs.

In applying the gate system, planners obtain resource data from existing inventories found in TRI with very little field work at gate 1. Prior to formulation of the GRC, it was difficult to provide geologic data at this vital initial step in the planning process.

By no means is the application of Geologic Resources and Conditions Maps limited to timber sale support. Figure 10 displays potential application of this data to other resource programs.

The policy at the Gifford Pinchot National Forest, as stated by the Forest Supervisor, is that TRI is the official Forest data base and will be utilized as such by all resource specialists. When evaluating the best place to put Geologic Resources and Conditions data in TRI, it was decided to create a new subsystem because the GRC is unlike any found in existing subsystems.

A user's manual, Geologic Resources and Conditions Subsystem Guide, has been written to explain sources of information, reliability, subsystem structure, significance of data, and application to resource management activities[1].

During 1983, the GRC maps were used in the development of several area plans that the Forest was converting from sale planning to larger planning areas with defined boundaries. The GRC maps were found to be beneficial in assessing the planning alternatives. Specific landslide problems are identified and low intensity field investigations are conducted mutually with transportation planners and geotechnical personnel to provide realistic costs to select the least costly road construction alternatives. During the same 1983 field season, three quarries were found using the GRD in areas of known rock shortages. These quarries have long-term benefits of several million dollars based on reduced costs for hauling, and the timber sales assigned for the initial entries will more than pay for the entire expenditures for the GRD.

Usually by the time specific site information is needed for design, the geotechnical specialists are familiar with the field conditions. They have completed the GRD and GRC maps and have been in the field where problems are anticipated in area planning. The priority levels for field investigations are determined on a Forest-wide basis, and the designers usually know ahead of time how much field data they will need. At the start of each field season the geotechnical group has a realistic work plan with backup information, which is reviewed by the Forest engineer to determine staff and budget needs.

In conjunction with the GRD, a study is being conducted in which existing slides are investigated to determine measurable factors causing failure. This information should improve ability of the geotechnical group to make evaluations in the planning stage.

The GRD was set up to assign several different levels of confirmation depending on whether the information was obtained by physical measurements in the field or projected. When field work is conducted methods are developed to recycle this information in the GRD. The information on the GRD will be continually updated and consequently more accurate.

SUMMARY

The GRD and GRC concepts has proven to have many benefits. Besides being tools to improve the technical adequacy of geotechnical information, they also provide a basis for early involvement in forest timber sale programs. The work is done in a more systematic manner which should result in reductions in overall construction cost and resource damage. On the Gifford Pinchot National Forest, there has already been enough cost savings resulting from their use to pay for the initial cost. With the GRD set up to be continually updated as project site investigations are completed, they will only become more useful in the future.

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[1] Geologic Resources and Conditions Subsystem Guide, on file at the USDA Forest Service, Gifford Pinchot National Forest Supervisors Office, Vancouver, Washington.

A COMPLETE THREE-LEVEL APPROACH FOR ANALYZING LANDSLIDES ON FOREST LANDS

Rodney W. Prellwitz

ABSTRACT: Land managers need a uniform and effective system for predicting landslide potential on forested slopes. No single geotechnical or statistical method is appropriate for all types of decisions. The USDA Forest Service in cooperation with the University of Idaho is therefore developing a system suited to three levels of application:

Level I. Resource allocation--provide managers with an overview of landslide potential adequate for developmental planning.

Level II. Project planning--predict response of slide-prone areas to various harvesting systems and transportation routes.

Level III. Critical site stabilization--evaluate stabilization techniques at critical sites before and after construction.

The proposed system incorporates geotechnical analyses, statistical analyses, and landslide inventories. Implementation is currently handicapped by inadequate data storage techniques and by the lack of methodology to measure and predict timber management impact on the two most dynamic variables: concentration of ground water and strength of tree roots.

INTRODUCTION

Resource management activities on many forest lands can accelerate mass erosion and cause significant degradation of water quality, fisheries, and esthetics. For successful management of forest lands an accurate assessment of the landslide hazard must support management decisions. The slope stability analysis technique, the data required for analysis, and the effort to acquire that data must be tailored to the specific decisionmaker's needs.

MANAGEMENT COMPLEXITY

The management of lands that have a high landslide potential is inherently complex, not only because of the nature of the interacting natural processes and management activities, but also because of the variety of specialists who must to some extent understand slope failure processes if they are to contribute to the total stabilization effort (fig. 1). Considerable overlap and interaction between members of key

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disciplines must be coordinated.

There are also several levels of intensity at which members of different disciplines must deal with the slope stability problems. For example, the resource planner must be able to recognize high-hazard areas, but only on a broad, general scale. The road locator must be able to recognize potentially unstable areas along proposed routes to minimize problems through optimum alignment. The engineer must be able to use soil mechanics in devising measures to prevent or correct failures of road cuts or fills.

CURRENT MANAGEMENT PRACTICES

Current management practices for dealing with landslides vary from forest to forest. Hazard analysis and treatment will usually follow at least one of the following patterns:

1. No formal analysis during the planning phase; the prudent land manager establishes a moratorium or reduces development in areas with landslide potential.

2. Landslide hazards are evaluated during the planning phase, using subjective ratings developed locally for identified landforms. Moratorium or reduced development may be exercised on landforms where landslides have resulted from road construction or timber harvest.

3. During the development phase, road locators or specialists may recognize slide-prone areas and use such knowledge in selecting the proposed route.

4. Following development, a detailed slope stability analysis is employed in correcting road-related landslides—without feedback into the planning phase.

Seldom do we find the proper slope stability analysis supporting decisions at all levels of management. This is mainly because there is no comprehensive system for evaluating landslide hazards.

IDEALIZED LANDSLIDE EVALUATION SYSTEM

Land mangers need a hazard evaluation system that begins early in the resource planning phase, follows through into the project development phase, and feeds information back to the planning phase to improve future analyses (fig. 2). The selection of technique should be commensurate with the level of management decision. The system should begin with a simple analysis that requires generally available resource inventory data for the planning phase and that becomes more complex and requires more exact data as the intended use demands greater accuracy.

Three levels of analysis complexity and supporting data are visualized for the system as outlined in figure 3. A more detailed description and a typical problem are given in an earlier publication (Prellwitz and others, in press). The application of the system is as follows:

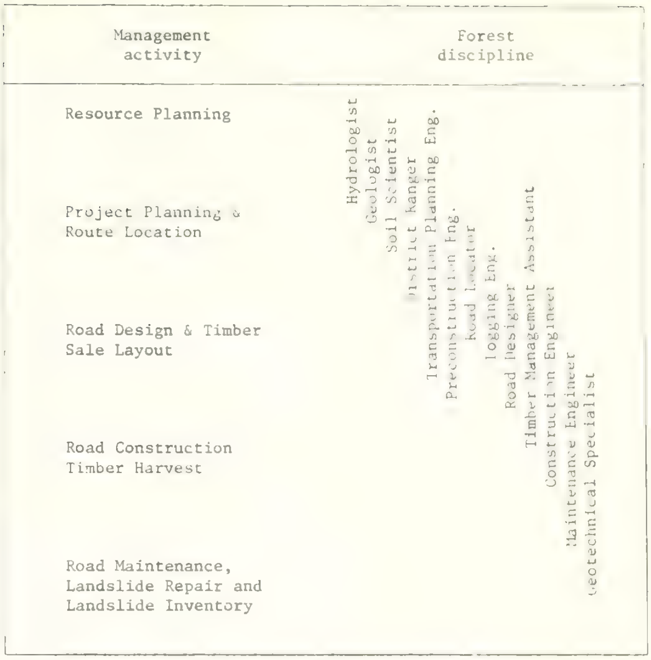

Figure 1.—Specialists involved in managing unstable forested lands.

Level I: Resource allocation.—Stability analysis delineates areas susceptible to landslides on a broad scale to alert the land manager to land units of greatest hazard intensity. The number and magnitude of landslides resulting from resource development can be predicted through statistical correlation to the landslide inventory.

Level II: Project planning.—Added complexity provides information to many additional users. The severity of instability can be more accurately assessed as local "islands of instability" and are identified through reconnaissance. Decisions can be made to limit development or to continue into the Level III phase based on an improved assessment of magnitude and intensity of probable failures. Timber harvest techniques and alternate route locations can be more closely evaluated. Perhaps the most important use is to isolate the critical sites along the selected routes for Level III analysis.

Level III: Critical site stabilization.—An analysis of increased complexity to facilitate the selection and design of road stabilization measures includes an analysis of stability—probability of failure—construction cost of all alternatives. Rock buttresses, drilled-in parallel drains, interceptor drainage trenches, retaining walls and changes in alignment, can all be compared and evaluated in conjunction with current management constraints.

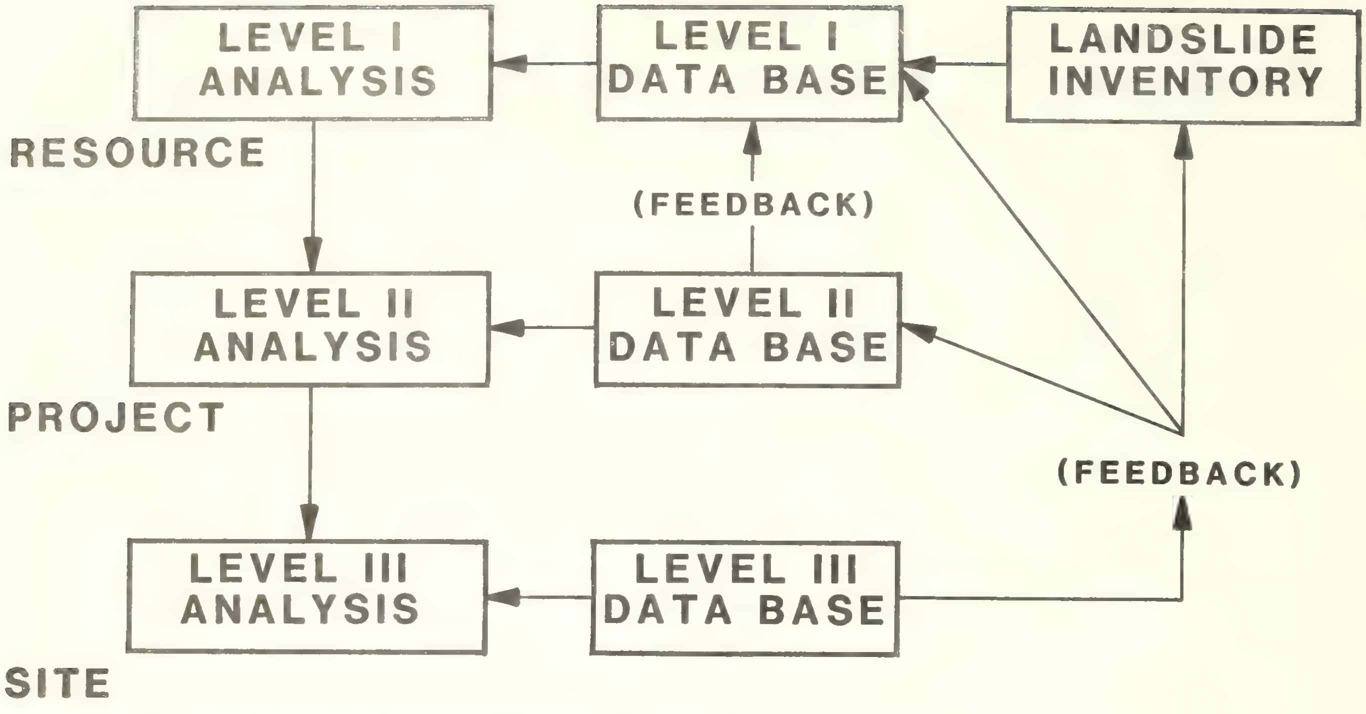

Figure 2.—Idealized three-level slope stability analysis.

Management activity	Analysis complexity level			Stability analysis			Base map			Input data base			Output		
				Level			Level			Level			Level		
				1	2	3	1	2	3	1	2	3	1	2	3
RESOURCE PLANNING	LEVEL 1 Resource Management			Infinite Slope			Resource Map Approx. scale 1"=2000 ft.			Resource Inventory, broad characterization of soil strength parameters, available landslide inventory			Hazard map overlay with factor of safety and probability of landslide		
PROJECT PLANNING & ROUTE LOCATION		LEVEL 2 Project Planning & Design			Infinite Slope and Critical Height			Project Map Approx. scale 1"=500 ft.			Blowup of level 1 map, additional input from route and timber reconnaissance, improved estimate of soil strength parameters, improved ground water prediction from response model, improved prediction of subsurface profile			Same as level 1 but more detailed showing local "islands" of instability. Unstable road cut and fill slopes on proposed routes	
ROAD DESIGN & TIMBER SALE LAYOUT			LEVEL 3 Critical Site Analysis			Method of Slices			Site Map and Stability Cross Sections Approx. scale 1"=20 ft to 100 ft.			Blowup of level 2 map, additional input from road survey, improved data from geophysical investigation, possible drilling of critical sites, refined ground water response analysis, refined soil parameter analysis			Same as level 2 of critical area, 3-D displays, critical cross section, input for stability analysis, results of stability analysis, relative cost comparison of stabilization techniques
ROAD CONSTRUCTION & TIMBER HARVEST															
ROAD MAINTENANCE, LANDSLIDE REPAIR AND LANDSLIDE INVENTORY															

Figure 3.--Idealized landslide evaluation system-soil mantle failures.

IMPLEMENTATION AND RESTRICTIONS

Existing Stability Analyses

Analysis technology is currently available to implement the proposed system. A program developed by Simons and others (1978) for mapping potential landslides is based on an infinite slope analysis and includes options for both "factor of safety against failure" and "probability of landslide occurrence" for a Level I analysis. Stability charts with seepage correction factors are being developed (Prellwitz 1975) and converted to computer programs for a Level II analysis of critical height of typical cut and fill slopes. Geotechnical specialists are using many programs to analyze and correct existing landslides. The most widely used methods can be integrated into one program to cover a variety of analyses of failure surfaces for Level III. Statistical counterparts for the "probability of landslide occurrence" options used in Level I are possible for Levels II and III based on methods currently used in geotechnical engineering (Simons and others 1978; Wyllie and others 1980).

Existing Data Base

Currently the system is handicapped by the limited data available for most forests. Many forest managers have (or are in the process of developing) resource inventory maps for soils, geology, topography, timber type, and other features. These maps could provide the basis for characterizing geotechnical variables to use as a Level I data base. The data base could be upgraded with use (Vita 1982). Statistical analyses used by Simons and others (1978) and DeGraff (1982) will prove invaluable for linking physical factors such as bedrock, aspect, and slope to inventoried landslides. The accuracy of the values assigned for geotechnical variables, analysis models, and the "probability of landslide occurrence" can be tested through association with corresponding physical factors. Currently, only a few forests have landslide inventory data. Geomorphic maps, where available, are based on major physical factors for identifying and assigning values to geotechnical variables.

Methods for Defining Variables

The main restriction to implementing the system is the difficulty in defining certain geotechnical variables. Techniques for determining slope, soil depth, and soil shear strength have progressed to a state where the values and their variance can be used with some degree of confidence. This is not true for the two most dynamic variables: (1) concentration of ground water and (2) strength of tree roots. There are currently no cost-effective methods for measuring or predicting timber management impacts on these two variables. The part of the soil mantle that can be expected to be below the phreatic surface at any time is perhaps the most dynamic of the variables. It can fluctuate constantly in response to precipitation. Practical and inexpensive methods are needed to develop local correlations between rainfall and snowmelt and the resulting rise in ground water. Although there is general knowledge about tree root strength within the rooted zone, there currently are no practical methods for measuring the effective strength that relates to the stability of the entire slide-prone soil mass. Until these techniques are developed, probable values and analysis sensitivity for these two variables can be estimated through analysis of existing landslides.

SUMMARY AND CONCLUSIONS

The concept for a complete three-level landslide analysis system has been outlined. Important points regarding the system are:

1. Each level of analysis is designed to provide guidance for land management decisions at that level only. Complexity, data required, and accuracy must be commensurate with the nature of the decision.

2. A loop that channels Levels II and III data back into the Level I data base will upgrade the accuracy of future analyses.

3. Although the system is intended for soil mantle failures, it may be applied to rock slope failures by substituting appropriate analysis techniques and data.

4. Analysis techniques are either available or are developable, but are currently little used because of two restrictions:

   a. Lack of a dynamic and easily upgraded data storage system.

   b. Inadequate techniques for measuring and for assessing timber management impact on geotechnical variables, such as concentration of ground water and effective strength of tree roots.

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DECISIONMAKING IN THE PRESENCE OF RISK

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ABSTRACT: Any assessment of risk must take into account both the severity of the possible hazard and the specific probability of that hazard occurring. This paper discusses the concepts of risk and introduces several of the different approaches to risk analysis, with particular emphasis on the way in which such analyses affect the ultimate determination of "acceptable risk" in managerial decisionmaking.

INTRODUCTION

Many public policy decisions are made in a context of risk; land management decisions involving the possibility of landslides are just one example. Most published studies analyzing such decisionmaking, quite understandably, focus on decisions having potentially dramatic and large-scale consequences: decisions regarding the siting of nuclear power plants or liquefied natural gas facilities, the effective control of water resources and sources of environmental pollutants, and the regulation of human exposure to carcinogens or other toxic substances. See the end-of-chapter references and the concluding bibliography in Crouch and Wilson (1982).

In many cases, public policy decisionmaking procedures are mandated to include detailed analyses of the risks inherent in the proposal; the risk assessments resulting from such analyses then often play a formal and prominent role in the decision process. Whether or not a formally prescribed, analytical procedure is followed, however, the decisionmaker bears the ultimate responsibility of determining the level of risk acceptable to society commensurate with the benefits to be received. Although this concept of an "acceptable level of risk" often comprises the key issue of debate in many public policy decisions, such a determination must first be preceded by a well-informed analysis of the risk itself. The purpose of this paper is to discuss various of the basic elements in such risk assessments, that managers in the USDA Forest Service might take into account in their landslide related decisionmaking procedures.

A DEFINITION OF RISK

Before discussing the various factors that might be taken into account in a complete risk assessment, the word "risk" should be defined. Unfortunately, "risk" is often used to represent several different concepts, as can be illustrated by the following three statements:

1. The risk of a landslide at milepost 2 is 1 out of 10 (that is, 10 percent).

2. The risk of a landslide at milepost 2 is that Fish Creek may be blocked.

3. The risk of a landslide at milepost 2 is simply unacceptable.

Statement 1 is a probability estimate that states the likelihood with which a specified

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event will occur. This probability (that is, the number 0.10) might result from a complex factor-of-safety calculation, or it might derive from an empirical process such as an on-site evaluation by an appropriate specialist. However obtained, the probability estimate alone does not indicate whether the occurrence of this event is desirable or undesirable, or whether it is benign or severe in its consequences. As such, this statement does not constitute a risk assessment.

Statement 2 is the description of a possible hazard--something that causes danger, peril, or difficulty. The actual occurrence of this hazard may be quite likely or highly improbable. Simply describing such a hazard, however, does not by itself constitute a risk assessment.

Statement 3 is a judgmental assessment of the risk posed by the hazard described in statement 2 when the hazard occurs with the probability given in statement 1. Here we are defining risk as "exposure to the chance of injury or hazard." This definition, therefore, requires that both a hazard and a chance (probability) be specified in order to describe the risk. Thus, any risk assessment must explicitly consider both the severity of the possible hazard and the specific probability of that hazard occuring.

WHAT IS AT RISK?

Most of the literature on landslide management focuses on techniques for estimating the probability of landslides in different types of terrain, and on descriptions of the adverse impacts of such mass land movements. These studies allow the land manager to assess exactly what is at risk in a potential landslide situation. Such elements at risk may include any of the following:

1. Human lives. In risk assessments involving such decisions as the siting of nuclear power plants or the introduction of hazardous substances into the environment, human lives are the paramount element at risk. Historically, in landslide-related management decisions, the danger to human life was not a relevant concern except in isolated cases. As residential construction encroaches on forested lands, however, this may become a decisive factor in many land mangement decisions.

2. Private property. This category includes damage to houses, other privately-owned structures, items of capital equipment, and degradation of farm and grazing lands.

3. Public property. Included here are public roads, bridges, and other structures; economically important public property such as timber stands and waterways; and a wide range of "public goods" in the form of recreational opportunities.

4. The environment. This category provides the major focus of landslide-related, land management decisions, particularly as the decisions pertain to the maintenance of water quality and fish habitat.

5. The organization. One element at risk that is rarely given explicit consideration in land management decisions is the organization itself. In the private sector, of course, the very existence of the business or industry may be at risk of bankruptcy. Although the Forest Service faces no such terminal hazard, the organization is nonetheless at risk in the following areas:

   a. Its reputation as an effective and trustworthy manager of public lands may be put in jeopardy.

   b. The credibility of its analyses supporting controversial new management initiatives may be lost.

   c. The opponents of specific management policies may become increasingly encouraged to pursue legal challenges to contested decisions.

   d. It may be forced to cancel activities for which substantial planning resources have already been committed.

6. The job. Another element at risk that is rarely given explicit consideration is the decisionmaker's job. In the private sector, the loss of one's job is an ever-present risk knowingly assumed by management personnel. It is unclear in what sense any analogous situation exists in the Forest Service.

TYPES OF RISK

In estimating the risk to any of the above entities, we must carefully assess the context in which the risk becomes imposed. Four important considerations directly affecting risk assessments in land management decisions are background risks, incremental risks, marginal risks, and differing boundaries of analysis (see Crouch and Wilson 1982, p. 17).

1. Background risk implies recognition of hazards that may exist independently of any management decisions. In the context of slope stability problems, background risk refers to the occurrence of landslides and surface erosion (sometimes in substantial amounts) even in the absence of land management activities. A complete landslide risk assessment will include an estimate of the degree to which various of the entities listed above are already at risk from strictly natural phenomena.

2. Incremental risk is a measure of the added risk, over and above the background risk, that would be imposed by the alternatives under consideration. In land management decisions, therefore, one would analyze the additional landslide risk resulting from proposed timber-related activities. A key methodological question in such risk assessments is whether the background risk should be "subtracted"--thereby basing the analysis solely on the incremental

risk from specific proposed activities--or whether the total (background plus incremental) risk constitutes a more appropriate basis for the analysis.

3. Marginal risk is a concept that encourages consideration of the cumulative effect of related decisions. In a land management context, rather than ask, "What is the risk involved in developing a unit on this watershed?" one would ask, "What is the risk of developing the next unit on this watershed? or the fifth unit on this watershed?" Whereas the risk of an isolated management decision may be calculated to be quite modest, the combined risk of several management activities to a common watershed might very well be found unacceptable.

4. The boundaries of analysis determine how broadly or narrowly focused the risk assessment will be. In addition to having clear direct effects, land management decisions will typically have a wide range of indirect effects. Such secondary and tertiary effects will quite likely impose their own risks, which might appropriately be added to those of the direct decision. As an example, consider the risk to the Forest Service if logging activities on a large watershed were curtailed by court order. A direct result of this decision might be localized unemployment of loggers, drivers, and mill workers, with an associated wider impact on the region's economy. In addition to such direct effects, however, we might imagine several indirect effects on the Forest Service.

a. To achieve the required cut, there may have to be more intensive harvesting on some other watershed, which would result in a higher-than-planned environmental impact in these other areas.

b. The local unemployment might result in significantly increased fishing, hunting, and camping in the forest, with possible adverse impacts on the resources involved (such as from excessive fishing pressure or from forest fires).

The obtaining of the court order might encourage other special interest groups to increase their efforts at litigation and further divert Forest Service resources to respond to such legal challenges.

GROUNDS FOR DISAGREEMENT

Decisionmaking under risk would pose no significant challenge if all parties always agreed on the best alternative, but this is seldom the case. Kleindorfer (1982, p. 183) points out that disagreements among interested parties can arise from either of two basic sources: conflicts of fact or conflicts of values.

Conflicts of Fact.

Because an assessment of risk is based on estimates of the severity and of the probability of various hazards, either estimate can be a source of disagreement.

1. Probability estimates for a hazard such as timber-related landslides may provoke disagreement because different conceptual or mathematical models (such as different factor-of-safety formulas) are being used by the opposing groups, because not all the constants or coefficients for these models are known (and thus require subjective judgement), or because extrapolation from known data points is required (without agreement on the correct methodology for the extrapolation).

2. Severity estimates for a specified hazard may also be subject to disagreement stemming from a lack of sufficient experimentation or scientific observation of the hazard and its associated effects. This may provoke either disputes over the validity or existence of presumed causal connections, or disputes challenging the ultimate severity of the hazard itself.

Conflicts of Values

The values that play the dominant role in most land management decisions involve either threats to the safety and health of humans or possible adverse impacts on the environment. Each of the concerned parties in a decision may view such impacts from a different perspective and with a different set of underlying values and priorities. Although one might hope that continued scientific investigation can resolve many of the conflicts of fact, conflicts based on values will almost certainly remain a critical element of dispute in decisionmaking.

If conflicts of fact reflect disagreement over the question, "Exactly what is the risk?" then conflicts of values motivate the question, "Is the risk worth taking?" To answer this question, it is necessary to identify whose values and priorities are to be decisive. If the central mission of the Forest Service is the effective management of the lands under its jurisdiction, then this requires identifying for whom these lands are being managed. Such a people-oriented perspecitve requires that the previous framework of analysis be restated; the focus of the risk assessment shifts from a concern over what is at risk, to an analysis of who is at risk.

WHO IS AT RISK?

When considering the groups of people at risk in landslide-related land management decisions, the temptation is to limit the analysis to those individuals adversely affected by the destruction of terrain, degraded fish habitat and reduced water quality, and economic displacement resulting from possible landslides. A more comprehensive analysis, however, would equally acknowledge the risks to individuals resulting from policies of restricted harvesting to minimize landslides. The individuals at risk in these land management decisions include the following groups:

1. Local Residents. Some residents of the local area might be at risk from the direct physical effects of a landslide; effects that include damage to privately owned structures and equipment and the effective loss of real property and domestic water supplies.

2. Local Employees. Employment may be temporarily interrupted by physical damage from landslides. A decision to reduce harvesting as a means of landslide control would clearly be much more damaging to the local employment situation, however: individuals would be at risk from a wide range of economic impacts that would affect not only workers directly involved in wood products industries, but ultimately the region's entire retail and service sectors.

3. Recreation Seekers. An entire class of recreation seekers and recreation providers is at risk from loss of fish habitat and forest access that might result from landslide acitvity.

4. Future Generations. One of the most difficult factors to incorporate into risk assessments for land management decisions is the time scale of an adverse impact. Evaluating the degree to which future generations, as distinguished from the present population, are at risk requires accurate estimates of the effective duration of the adverse impact and appropriate incorporation of such information into the risk assesment process. Such analyses are important for decisions in which relatively severe environmental impacts might still be found to be "worth the risk" if the environment were capable of being restored to its previous condition within a relatively short period of time. For example, a potentially severe loss of fish habitat might be judged an acceptable risk if it were shown that the habitat and associated fishery would return to its prior condition well within a decade.

Although we have suggested addressing the question "Who is at risk?" as a basic strategy for the assessment of risk, it is worth emphasizing that risk is a pervasive condition under which we all exist. People are at risk every moment of their lives, not only from possible adverse consequences of their own actions, but also from direct or indirect effects of the decisions of others. Accordingly, it is totally unrealistic to seek a decisionmaking strategy under which individuals are not put at risk. But even if one accepts the premise that putting individuals at risk is an inherent and inescapable element of any decisionmaking, it is important to understand the special factors in public policy decisions that can make risk assessment such a controversial and emotional process.

PSYCHOLOGICAL FACTORS

Many studies have identified factors that appear to affect the public's assessment of risks in public policy decisions; see, for example, Slovic et al. (1980) and Kunreuther (1980). Most such studies, however, have focused on decisions involving potentially dangerous and controversial issues such as the siting of nuclear power plants or liquefied natural gas terminals, the introduction of toxic substances into the environment, or the exposure of individuals to suspected carcinogens. For these decisions, a set of psychological factors has been identified that appear to assume great importance in influencing public decisionmaking. Although the applicability of these factors to landslide-related land mangement decisions is in some cases only marginal, they are worth summarizing here. (For a more complete treatment of this subject, see Lathrop [1982].)

1. Possibility of Catastrophe. What seems to differentiate a catastrophe from other similarly adverse circumstances is some sort of "bunching" of events, whether bunched by cause, by location, by period of time, or by state of nature. For example, the most severe accident that could conceivably occur at a nuclear power plant might cause the near-simultaneous death of a large number of people within an area and would certainly be considered a major catastrophe. Yet more people, by far, die every year from traffic accidents or from the effects of smoking without provoking even a fraction of the public concern aroused by the extraordinarily low probability "catastrophic" hazard. This psychological phenomenon forces public policy decisionmakers to bias risk assessments away from catastrophic events, even though their probabiliy and relative adverse consequences might otherwise qualify them as quite acceptable risks by other societal standards.

2. Considerations of Equity. In public policy decisionmaking, risk assessments can also be stongly influenced by the public's perception of equity in the risk. There are at least two types of equity considerations that might provoke such public concern.

a. Many public policy decisions would cause the risks to be borne by a different segment of the population than would receive the benefits. Such inequity, for example, exists when a power plant located in one populated area sends its generated power to a distant metropolitan region. (One assumes that this distinction becomes less persuasive, however, when the population exposed to the risk voluntarily make their livelihood by virtue of that activity.)

b. A second type of perceived inequity would result from the possible identification, as part of the risk assessment, of specific individuals who will be adversely affected. As an extreme example, a public policy decision that would very likely result in one additional death annually in the local vicinity might still be considered an acceptable risk, whereas a similar decision that would result in the death (with the same high probability) of a single, clearly identified individual would almost certainly be declared unacceptable.

3. Voluntariness of risk. As just suggested, the consideration of equity in risk assessments is strongly influenced by perceptions of whether or not the risk is assumed voluntarily. This determination, in turn, is often closely linked to the question of necessity of exposure to risk, which defines the degree to which the risk can be considered to be voluntarily assumed by the individuals so exposed.

4. Participation in the decision. It is understandable that the acceptance of risk assessments in public policy decisions often depends on the degree to which affected parties feel they have participated in the decision. The ultimate impact of such participation, however, is often constrained by the range of alternatives available to the decisionmaking authority.

5. Attributability of the risk. A given risk may be more easily tolerated by the public when no specific entity can be identified as the cause of possible adverse impacts. It is easy to imagine a variety of severe environmental disruptions that would be considered unfortunate, but not disastrous, if they were the result of an unforeseen "act of God," but which would prompt cries of outrage and would be charcterized as total ecological disasters if traceable to specific human interventions.

6. Nonprobabilistic Reasoning. This phrase expresses the tendency of some individuals to forsake probabilistic reasoning altogether in their assessment of certain types of risks, and instead to base the decision solely on descriptions of the maximum potential hazard irrespective of its probabilty of occurrence. In some cases such behavior may result from an individual's inablity to understand probability estimates or to comprehend adequately the meaning of extremely low probabilities. In other cases, the individual may simply doubt the accuracy of the probability estimates and choose, therefore, to ignore such estimates in analyzing the decision. Another explanation that should not be neglected, however, is that even at extremely small probabilities some hazards may be so dreadful to contemplate that persons so exposed would lead lives of constant fear--even if it were totally irrational to do so. If one accepts the notion that dread constitutes a social cost, then such considerations will inevitably influence public policy risk assessments (see Burness 1981).

7. Familiarity of the risk. The problem of nonprobabilistic dread tends to diminish as the risk becomes more familiar. In many cases the degree of public concern also diminishes. Almost by definition, the most familiar risks will be those that occur the most often, and this brings our discussion back to the first point mentioned in this section: familiar risks tend not to be considered catastrophic and, at the extreme, simply become part of the background risk that is accepted as a normal part of one's existence. So it is, for example, that traffic fatalities (which claim more than 50,000 lives in this country each year) and smoking (which results in an annual death toll estimated at 150,000 lives) have become such familiar risks as to be virtually ignored in the everyday risk assessments of ordinary citizens.

CONCLUSION

This paper has not attempted to answer the question "What specific level of risk is acceptable for landlside-related land management decisions?" nor is it likely that such a question could be answered in any general fashion. It is obvious that public policy decisionmaking in the presence of risk cannot be treated as a process depending solely on mathematical analyses of risk factors, but must be seen as a process incorporating complex, and often decisive, psychological and political considerations. This paper has focused on various of the nonanalytical elements to which the decisionmaker should be sensitive when assessing risks and presenting potential risks to the public.

There is, of course, the need for managerial understanding of the way in which a mathematical analysis of risk enters into the risk assessment methodology. Several papers describing specific methodologies for risk assessment appear in Kunreuther and Ley (1982). Of particular interest are descriptions by Mandle and Lathrop (1982) of different types of analyses used in risk assesments for the siting of liquefied natural gas terminals, and an account by Oseredko and others (1982) of the analysis for the routing of a main gas pipeline. An extremely detailed presentation of the mathematical analysis needed to support a major public policy decision (in this case, the siting of nuclear power facilities) is presented by Keeney (1980).

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PANEL DISCUSSIONS--LIMITATIONS AND NEEDS FOR EFFECTIVE LAND MANAGEMENT RISK ASSESSMENT OF POTENTIALLY UNSTABLE TERRAIN

Question Before Panel 1: What levels of political/social influence on "risk" are appropriate in forest land management decision-making?

Speaker 1: DAN BIGGER--This question is provocative, but difficult to address. The Washington State Department of Natural Resources is concerned, both as a forest land management agency and as a regulatory agency, about unstable forest land. My response to the question involves the department's regulatory role and is guided primarily by the language and purposes of the Washington Forest Practices Act (Chapter 76.09 RCW) and the Forest Practices Rules and Regulations (WAC 222).

The Forest Practices Act defines public resources as water, fish, wildlife, or State and local government capital improvements. All reasonable methods of technology are to be utilized in the protection of forest soils and public resources while recognizing both public and private interests in profitable timber management.

The varied purposes of the Act and regulations require the department to exercise judgment and to specify the preventative or corrective actions or the mitigation measures necessary to minimize damage to public resources. To be effective, the regulations must be administered in a reasonable manner and the department needs the active support and cooperation of forest landowners and timber harvesting operators.

Forest practices that displace significant amounts of soil and rock on unstable slopes are regulated and the department will analyze soils hazards, proposed road construction and timber harvest operations. The department will recommend feasible mitigation measures that may include alternative proposals for roads and harvest methods.

Although not specifically addressed by forest practice regulations, the department will also consider risks to life and property, cumulative effects of harvesting on-site and off-site, and the political consequences of slope failures. Where the forest practices rules require mitigation of potential damage, but no feasible methods exist, an environmental review process may be required. Where the State Environmental Policy Act (Chapter 43.21 C RCW) and Rules (WAC 197-11) govern, an environmental impact statement may be required and the proposed forest practice is subject to approval or disapproval based on environmental considerations. Environmental considerations include much more than protection of public resources.

There are few tools and limited technology to assess the potential of slope failure on forest lands. Fortunately, Washington has a comprehensive soil survey, and unstable soils have been identified and mapped. Soil interpretations have been developed and field personnel have received introductory training. Some of the problems have been identified, but reliable solutions have not. Regulations, alternatives for road construction and harvest

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methods, and various mitigation methods only help reduce slope failures. There are no guarantees that any of these approaches will be successful. The department and landowners must contend with possible slope failure site by site.

Speaker 2: PAUL SWATECK--The long tradition from which today's conservationist comes stresses stewardship and wise use of natural resources. This immediate generation has responsibility to utilize renewable natural resources in a fashion that passes the resources on to the next generation with productivity unimpaired. Conservationists see a forest as a community of soils, vegetation, animals, air and water--interdependent and linked. Society's responsibility for stewardship reaches beyond human concerns to the protection of the integrity of this community for its own sake.

To a remarkable extent, the public has embraced these conservation values. The statutes in this country require evaluation of potential environmental impacts through the preparation of impact statements, call for multiple use of our forest lands, and regulate activities on both public and private lands to protect public health and prevent nuisance. This society requires reclamation of strip-mined lands. There is a recognized public interest in protecting navigable waters. The states look out for wildlife. Our government operates by a set of administrative procedures that gives the public rights to participate in decisionmaking regarding environmental matters, and a strong network of groups dedicated to the protection of nature try to follow and influence activities affecting their interests.

This is the context in which decisions about forestry operations are made. Assessing the risk of mass failure from roading and timber operations is not just a technical matter to be handled by the engineers. It also needs input from fish and wildlife professionals, from those concerned with water quality, from land use planners, and from the general public that uses the resources affected. There are social, political, and even ethical considerations beyond the technical dimensions to assessing risk.

It is important to recognize that risk is not just a question of probabilities. The probability of slope instability may be low in absolute terms and still be unacceptable to a party being asked to absorb the impact of failure while deriving no benefit from the activity precipitating the failure. This is to say, there are important distributional dimensions to assessing risk. Too often, interest groups desiring to obtain a benefit for themselves are willing to overlook the problems that fall to others. The problem may be loss of fish spawning beds, decline of water quality, or loss of recreational amenities. Other parties may be commercial fishermen, sportsmen, recreationists, or neighbors. These parties must have access to the risk assessment process and to the making of risk-taking decisions, when they desire it, for their interests to be protected adequately. They need to be assisted by the best technical, and engineering and legal expertise available. Conservationists believe however, that the assessment is best done as an interdisciplinary exercise and integrate technical, biological, political, social, and ethical considerations.

There are various ways to resolve potential distributional risk problems. The one that is unacceptable to conservationsts is to ignore the risk and let the victims of failure end up bearing the costs of failure. Most situations present a system of potential tradeoffs among the interests involved. If all affected parties are involved and empowered to affect the outcome, it is often possible to negotiate an acceptable compromise. A set of uniform rules to establish basic protection is desirable to provide a standard of performance for industry and to protect underrepresented interests.

There also needs to be a mechanism for dealing with failure. Repair of problems arising from mass failure can be very expensive. A system of liability for the operator who derives the benefits of the risk-imposing activity and penalties in the event of failure is needed both to pay for rehabilitation and to create an incentive for good performance. Bonding requirements and liability insurance, tied to an improved technology for assessing risks, and proper incentives for good performance are needed to allow the carrying out of risk producing activities acceptably.

Conservationists recognize that natural systems are dynamic. Preservation of the status quo is not natural or even desireable in every instance. Mass failure is a part of the natural cycle of many watersheds. We have found, however, that human activities which accelerate natural geological processes too much can overwhelm natural restorative processes. These activities usually have complex cumulative effects that make it difficult to establish cause-and-effect relationships. Managers need to gain a better understanding not only of the assessment of the risk of mass failure but also to learn more about natural restorative processes and how to conduct repairs when necessary.

Conservationists support this kind of conference. I have been the environmental cochairman of the Western Forest Environment Discussion Group, which has representatives from conservation groups and the timber industry in the Northwest. The group has been involved in a dialog for 7 years. Field trips were conducted

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PAUL SWATECK was conservation administrator for the Sierra Club in San Francisco from 1975 to 1983, and served as environmental co-chairman of the Western Forest Environmental Discussion Group. He currently resides in Lafayette, California.

in 1980 and 1981 to review mass failure problems and approaches for improving risk assessment technology.

Conservationists want to see the most knowledgeable experts in geology, soils, hydrology, engineering, and other relevant disciplines meet and learn from one another and improve understanding of the processes involved in mass failure and predictive capabilities. We want to see biologists join in assessing the impacts of mass failure on the streams and rivers and to the wildlife populations. We want this technical information made intelligible and available to the public and government decisionmakers who grant permits for risk-producing roads and timber harvests. We want the public to be involved.

If managers are smart in doing this work, they will preserve the land and soils base, maintain the harvest, reduce avoidable adverse environmental impacts, and reduce conflict.

Speaker 3: R.T. BAILEY--The question of what levels of social/political influence are appropriate in risk decision making on unstable forest terrain must be put in its proper perspective. Many novices in the world of forest land mangement hold the false conviction that nearly all the mountainous forest land in the west is unstable and any management activity will cause landslides and severe erosion. It is therefore important to understand the relative magnitudes of "high-" and "low-risk" terrain.

Over the past few months I have been heavily involved in what is known as the "Mapleton Lawsuit" in which the National Wildlife Federation brought suit against the Mapleton District of the Siuslaw National Forest in the Coast Range of Oregon alleging violation of the National Forest Management Act, Multiple Use Sustained Yield Act, the National Environmental Policy Act and the the Church clearcutting guidelines. The National Wildlife Federation charged that the forest soils of the Mapleton District are among the most erodible in the United States and that unacceptable resource damage to the soils, watersheds, and fish habitat would occur as a direct result of harvesting on unstable, "high-risk" soil types.

Although many acres of forest land in the west are perceived as being "unstable" by the public, in reality only a very small percentage is actually in that category. For example, out of the 16 million acres of commercial forest land in the USDA Forest Service, Pacific Northwest Region (Washington and Oregon), only 184,000 acres are considered unsuitable for timber production because of the potential for irreversible resource damage--only about 1.1 percent. The supposedly erosive Siuslaw National Forest has only 14 percent of very high risk lands, while only 0.3 percent of the land base is in actual landslide area. Is undue attention given to this issue? Are we as managers putting 95 percent of our effort on only 5 percent of the problems? And even though landslides do occur, are they causing any damage to the water or fish? I don't know the answer to these questions, but even if professional resource managers get most of the criticisms on that 5 percent of the land base, they must not forget the real and difficult problems on other lands as well.

Risk in Resource Management

Other speakers here have talked quite extensively about what "risk" is and what "instability of slopes" means. What I want to talk about is the importance of protecting assets in the face of uncertainty. Perceptions are sometimes more damaging than any action, particularly with respect to land management. I've heard, seen, and discussed with many people their perceptions of objectives of industrial forest-land owners. To sum it up briefly, the mythical timber baron lives in the public conscience--I might add, in the minds of some of the regulators and public agencies as well.

What does this mean in terms of risk? The perception is that the timber landowners will risk a great deal to be able to supply their mills or markets with wood, regardless of the land management restrictions imposed along the way. After interviewing 8 timber industry executives, I confidently say that nothing could be further from the truth!

The industrial land manager (or owner) is responsible for a tremendous asset, that, at his disposal, must be managed in a prudent manner or it loses value. The manager has a great interest in preserving the land to grow trees because the product and returns from this asset are the ultimate objective. Landslides are usually not the most productive sites for growing trees. The asset value is the lynch pin upon which all decisions must pivot, but that is not to say that all factors in the decision are monetary. There are a host of factors in each decision regarding unstable land that are not monetary.

The managers want as stable a road as possible--roads require a heavy initial investment which must be protected. Any road that slides because of poor design or maintenance becomes another unnecessary problem to pour more money into. As the past few years have shown, money is scarce.

Where does this leave the manager in terms of risk in decisionmaking? Again, a little perspective is necessary. There is nothing in this world without risk. Just as there's a risk in driving to work each morning so, too, is there

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risk in building roads and harvesting timber. In the investment world, people are known as "risk takers" or "risk averters"--takers invest more in volatile stocks (new issues, common stock, etc.); averters invest in stable items (municipal bonds, preferred stock, established companies).

Each of us lives in one of these risk classes--some of us prefer higher risks in some things and lower in others. There is no activity or action that is without risk. The cost of a relatively risk-free society would probably exceed the total U.S. Gross National Product. Many in the environmental movement or in Government may prefer that a lower "risk" be taken in resource management activities (for example, large buffers, minimal harvest, lots of mitigations) while at the same time, they may live their lives under a different risk preference. Mr. Swateck, of the Sierra Club, for example, sitting next to me, may prefer a lower risk in resource management, but he also happens to work in San Francisco. You wouldn't get me to live in California along the San Andreas Fault--it is too risky--that place is going to fall into the ocean!

The Forest Service people, State people, and industry people all have (as a class, if you will) a different risk preference that has developed through growth, personal experiences and organizational goals. While some in the public agencies have adopted the "infinite value syndrome" (that is, avoid all risk in certain areas, regardless of the cost), the industrial owner cannot afford that stance. While an agency manager may avoid unstable lands or difficult to reforest lands and remove them from the timber base (with purportedly no cost), the industrial landowner pays taxes each year on those acres, and in addition, has a large initial investment in them. If a reasonable return can be made, it should properly be sought. Thus the attitude shifts to how can these objectives be met. It may cost more and be more "risky" to operate on unstable lands, but a can-do vs. a can't-do attitude prevails. The weighing of social goals, such as wood for markets and homebuilding vs. the amount of risk on the landscape, is always a factor in the back of the decisionmakers mind.

Risk Factors

What are the risks in managing unstable lands? From an industrial perspective, the risks of losing land or roads through poor management decisions not only affect the asset value of land that managers are entrusted with, but may lead to a host of other negative implications that may be more serious, long lasting, and risky than just the physical impacts of a landslide. What I'm talking about is the ever-present risk to industrial landowners of the political reaction. The expense of environmental litigation with the attendant removal or limitations on private property rights is always there as is the ever-present increased regulatory threat. Changing public policy, tax rate determinations and increases, land use zoning, a biased media, and a credibility gap are also important parts of the "risk equation" that the industry operates under. Benefits and costs loom large in each decision, yet the cost factor is not all in dollars.

A potential risk factor that may seem extreme to some of you is the nationalization of timberland, including private lands. A push for timberland nationalization occurred in the early part of the 20th century when there was a strong belief that we were headed for a timber shortage and only nationalization and federal control would solve the problem. In fact, the origins of my organization trace back to this period and an effort at self-policing the industry for proper forest management standards. The National Tree Farm Program also got started at that time for much the same reason.

So risk takes many forms in the industrial perspective. No one likes to be told what to do, but this is always a threat. The stockholders (investors) of a company are very aware of the implications of mismanagement or increased social and political pressure and they do react by changing their investments.

One final note on unstable lands. It must be remembered that the mountainous regions of the West, indeed everwhere, are a function of uplift and erosion. If a slide occurs on the landscape, there's a good probability that the same land has slid in the past. Thus, the question becomes "how much does land management accelerate landsliding?"

During the Mapleton District lawsuit, several hydrologists commented that while it's entirely probable that management activities may alter the timing of an event and increase erosion rates over a short time period, long-term average rates are not increased or altered at all. Landslides are an event of nature and impacted areas nearly always recover, and while harvest activities may alter the equation a little bit, such activities are not going to overshadow these natural events. The Mount St. Helens eruption, the forest fires around Tillamook, Oregon in the 1930s and the great Pacific Northwest floods of 1964 all remind us of these natural events. In addition, the question of actual, physical, measurable damage must be answered. Landslides occur, but if they did not damage anything, how concerned would we be?

Changing Knowledge

Managers and practitioners are learning more about harvesting and building roads in relatively unstable land. Much effort by both public and private interests has been made to improve our abilities for avoidance and mitigation of unstable terrain. Improved road design and better maintenance programs combined with an ability to identify unstable situations have contributed to less problems for management. Private landowners share, along with the public and public agencies, a land ethic that requires prudence in managing the Nation's timber resource.

While each of us has our particular biases and preferences, we must not misuse science to achieve personal goals. There's already too much of that as the Mapleton suit demonstrates. Science must be kept objective or it helps no one.

Speaker 4: JOHN T. DRAKE--There is no single appropriate level of social or political risk. Risk is always there in varying degrees and often dictated by outside factors. As I see it, an acceptable level of risk is highly dependent on the sensitivity of the area, on resource values, and on the social and political setting. I might also say that from the National Forest perspective, risk varies significantly based on whether an issue is national or local.

There has been considerable discussion on risk during this workshop, but "risk" needs to be broken into components to be understood. Certainly the physical risk or resource risk is something the Forest Service has dealt with for some time. It can be defined reasonably well. Defining the political and social risks is much more difficult, and interrelationship of these two influences complicates precise assessment. I think the most productive approach, so far, has been to try to keep the total physical risk as low as possible while maintaining the economic viability of a project; both of these factors adjusted to reflect the needs and requirements of current political and social concerns.

At the practical level, the forest land manager must handle the existing risk with the given restraints rather than contemplating what is an appropriate level of risk to deal with. I think it is important that practicing forest land managers recognize risk is there; understand the level of risk acceptable under existing physical, social and political constraints; and try to deal with risk in as positive a manner and as early and as openly as possible in the planning process.

Speaker 5: NEIL SKILL--Let me talk to you about the social and political arena the State Department of Forestry operates in when administering the Forestry Practices Act in Oregon.

I think that society has come to realize, and experience in management of state lands has shown, that the public welfare cannot be adequately protected by leaving the entire matter of forest management on private lands to private enterprise. What is needed ideally is the establishment of public policy that will prohibit or reduce the possibility of exhaustion of a particular resource for private economic or limited interest purposes. Such policy should also prohibit significant lowering of our standard of living as we try to use that resource now and in the future. And finally, if there is a potential for exhaustion, the policy should institute controls or remedies now that will prevent exhaustion in the future.

This is a difficult job to accomplish. It is not uncommon for those of us faced with management of state forest lands to resort to some kind of regulation, such as the forestry practices acts that we see in states having a major forest industry. This is done as well at the Federal level; for example, the Federal Water Pollution Control Act, the Clean Air Act, and the Resources Planning Act. Even at the local level there is a trend toward more effective landuse planning by counties and municipalities.

I don't think there has ever been an entirely successful public policy to deal with natural resource protection and allocation, largely because there has never been a clear definition or understanding of what natural resources in the United States ought to be. Managers like to think that economics is a controlling factor in this definition, but actually political, social, and environmental factors may have equal or greater importance depending on individual points of view. From a public agency perspective, there is no choice but to deal with all of these factors in as unbiased a fashion as possible. There is no real separation between economics, politics, and public welfare; all are closely intertwined and all may be in conflict. I suggest that there are four distinct areas of conflict to deal with in any kind of development and administration of public law operating in the area of stability management.

The Role of Government

Over the years of development and administration of the Forestry Practices Act in Oregon, a whole range of people and organizations have attempted to influence the policy-making process. The Oregon Department of Forestry trys to respond to each of the sometimes conflicting needs or demands, but because of the poorly defined grey areas encompassing these various concerns the State must rely heavily on the political process for final formulation of policy decisions.

The Role of Special Interest Groups

Special interest groups perform the very necessary role of bringing various individual points of view together and putting them into

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some sort of framework understandable by a decisionmaking body. The problem that policy makers on the Board of Forestry face is trying to determine which group's interests are to be sacrificed. In making such determinations, the question of allocation becomes a very real thing that has to be dealt with. Here help is needed from scientists and technical field specialists.

The Role of Science

Science is a tool that managers have tried to use with various levels of success. As in other areas of resource policy, though, managers find that science does not always have the answers that are needed. Management needs basic information, facts, in a format suitable for making effective policy decisions. As we have heard in this workshop, there is good information available but there are still many areas that need work. Many scientists apparently have their own biases and tend to substitute their own objectives and data interpretations for those of society. This just confuses the issue.

Planning for the Future

To develop an effective and evolving resource management policy managers must somehow predict what is going to happen in the future. Herein we have major problems simply because with the existing level of knowledge it is necessary to make vague assumptions and use these to develop methodologies that have not been fully tested. When applying these methodologies, managers are imposing restrictions on the use of resources now to protect the future but without adequate justification. This is a major social-political conflict and much more information is needed to justify the regulatory decisions currently being imposed.

My final answer to this panel question is that there is no appropriate level of political and social influence on risks. In terms of the Oregon Forestry Practices Act, public policy is made by a number of people and groups acting to influence their particular positions or their points of view. What the Oregon State Department of Forestry has to do is provide every oportunity for people to have access to the decisionmaking process. State, community and public needs and demands must be weighed and the best possible decision made to minimize risk given the existing social and political environment. The agency also needs to maintain a constant search for improved techniques to reduce adverse social and political impacts from policy decisions.

Question Before Panel 2: How do the concepts of risk influence field decisions?

Speaker 1: SOTERO MUNIZ--The question before Panel 2, stated another way, is, how do managers cope with the problem of assessing slope stability risks in their land management decisions? Land managers, by the very nature of their responsibilities, cope with risk assessment daily. Because risks are assessed daily, the skills managers surround themselves with are one expression of the manager's assessment of the risks. For example, a public land manager whose lands are laden with fuel and have a history of wildfire will organize, staff, and budget for the expertise and tools necessary to minimize fire risks and, therefore, losses. Another manager with different combinations of resources will organize, staff, and budget differently, but will concentrate capabilities in those resource areas with the greatest values and subject to the greatest losses; the objective is to minimize risk.

Risk assessments by managers always involve a blending of subjective and objective data from the manager's own expertise, from the scientific disciplines, and from the expertise of the involved staffs.

The points made thus far are that managers assess risks daily and that judgment and decisions depend on the synthesis of the subjective experience, objective data, and analysis.

Managers have extreme difficulty in coping with problems of slope stability if subjective experience is limited and objective data is lacking. Scientists and technical specialists make the manager's job difficult, if not impossible, when the language used is too technical or too specialized and the recommendations are tentative or inconclusive.

One principle purpose of this workshop is to expose managers to relevant, state-of-the-art information about slope stability. This exposure will increase the manager's knowledge and experience and, therefore, improve the decisionmaking process.

If the manager's needs for information on quantifying risks are known, then criteria can be established for organizing the broad and hetrogeneous body of knowledge on slope stability into its most useful form.

I've listed some of the needs and conditions facing managers today in order to clarify what I believe needs to be considered as the concepts of risks and their influence on field decisions are

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addressed.

1. All managers are implementing cutback management. As a result, managers do not need and cannot accommodate recommendations to:

a. Increase technical staff or

b. Undertake extensive new inventories or land classifications to map unstable terrain.

2. Managers need clear and uniform guidance from higher organizational levels on particular data that is required for slope stability-affected decisions. For example, if higher levels of organization need to know how many acres of land have been subtracted from the productive land base because of slope stability problems, the managers need clear definitions of terms, categories, and direction on how to display the results.

3. Managers need to have a body of knowledge to assist them in analyzing slope-stability related problems. This knowledge must be made "user friendly" and must synthesize geology, hydrology, pedology, soil mechanics, and risk analysis.

4. Managers need to minimize data collection needs. They therefore need to use, as much as possible, associated data that has been inventoried for other purposes to satisfy slope stability questions.

5. Managers need to know if advanced technology is available to help with slope stability recognition, evaluation, and analysis. If remote sensing, color infrared photography, and associated technologies are available, managers need guidance on their effectiveness, costs, and availability.

6. Managers also need some guidance on the best source of expertise available. In some instances, this is self-evident--but what does a unit do that may have some problems but no technical experts?

7. Managers need to know what kind of training is needed and available to develop the level of expertise needed for making decisions regarding unstable lands.

I'm not fully conversant with the content of the extensive "Interstation Soil Mass Movement Research Program" begun in 1972. Perhaps some of the managers' needs listed here have already been accommodated. If they haven't, it may be timely to update the needs of managers and adjust future efforts to satisfy these needs.

In conclusion, knowledge and risk are intimately and inversely related. The challenge is to define the affordable boundaries of knowledge needed to manage unstable lands. As these boundaries are narrowed, the managers can continue to be relied on to approach risk-taking situations as directly as they always have, but with more competence and confidence.

Speaker 2: **LEO W. WILSON**--As director of Forestry Practices in the state of Oregon, I deal directly with a unique group of professionals. They are loggers. Somehow in their daily activities they have to make money, and this fact is very influential in their operational decisionmaking. I want to approach the question before this panel from the perspective of such operators.

The Oregon State Department of Forestry deals with over 11,000 operation notices a year, about the same number as the State of Washington. Most of the logs are moved by contract loggers working for private companies and often working on State, private, and public lands. A great many of the things happening to these operators are determined by the Oregon Forestry Practices Act. Operators must comply with the Act and attempt to make money in the process. The biggest single factor facing them is an adequate assessment of risk before they enter unstable pieces of terrain. As a public agency the Oregon State Department of Forestry must assist them as effectively as possible in avoiding trouble. This must be done while recognizing that they are a private enterprise and have to make a profit to stay in business.

A major problem facing these people, particularly in relation to construction of forest roads, is that building roads in unstable terrain is expensive. Engineering design costs are higher in unstable terrain, and full-benching, end-hauling, bin-wall construction, and other mitigation techniques are added expenses. Many times, operators will get into a contract situation where they must have a road from point A to point B to reach the logs and take them to a mill. In the process they may not recognize the risk they are getting into. The geotechnical expertise necessary to design such roads at minimum risk many times is not always available. Managers and specialists with the Oregon State Department of Forestry know that many of the stability problems in Oregon, particularly in the Coast Range, are road related. One of the new rules passed by the Oregon Board of Forestry and promulgated in September 1980 states that operators will minimize road construction. That is fine, that is a very noble goal. But a great many of the needed road systems are planned or constructed to accomodate a particular company's existing logging systems or equipment they have available. To minimize road construction may require shifting to different systems at a tremendous cost to the operator.

Another problem that is a concern when dealing with land owners of smaller parcels and limited capital is that we are going to have some soil mass movement because of natural erosion processes. It is necessary to convince such

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LEO W. WILSON is director, Forestry Practices, Oregon State Department of Forestry, Salem, Oregon 97310 land owners that some things they do will accelerate the process more than will others and that the increased costs or revenue losses incurred to reduce accelerated soil mass movement are necessary.

Something that is very difficult to deal with in the private sector is the requirement of leaving some ground uncut, or virtually uncut to prevent landslide damage. These problems and the costs of special yarding techniques, debris removal, and relocation of landings to reduce risk constitute major economic burdens on the operator and land owner.

The land owner and operator will become increasingly involved with damage litigation and repair to streams impacted by debris avalanches.

Cost analyses by the operator for many of these practices are going to be very difficult. Conclusive research results that can be applied are not always readily available. The decision on whether or not to log some areas may ultimately be based on whether or not the logs can be obtained elsewhere for less cost.

These are only a few of the factors used to consider risk from harvesting on public and private lands in the State of Oregon. All are important. There are no simple solutions or easy decisions. It costs more money to operate on unstable ground and, as costs increase, each decision becomes more important. When the operational "break-even" point is reached, the decisions become critical. Operating on unstable terrain will require careful planning and careful decisions at every point of the process.

Speaker 3: MELVIN L. KESSEL--Depending on the degree of the predicted risk, decisions are made to defer a project or to proceed with a project and to accept the risk. If the decision is made to proceed, usually every practical means is taken to mitigate the risk to acceptable levels. The perceived acceptable level of risk differs with individuals. Some managers will choose to cut trees while other managers will walk away. Decisionmakers have various comfort levels with risk. One may be very comfortable operating mostly with high-risk decisions; another may want everything guaranteed. There is a pitfall here. In this workshop we saw some formulas on how to determine certain things through engineering. Some managers believe that you can get answers that are either right or wrong from such an approach. I do not believe that. I think you get grey areas that are neither right nor wrong, but that provide indications of which direction a decision should go.

Two things managers have to determine are the "comfort level" acceptable to them when they harvest trees and the "comfort level" when they say they can't harvest trees because of unacceptable risk. When making these determinations they must be able to convince their supervisors that assigned targets cannot be met.

The size of a project can influence how much risk a manager is willing to accept. If it is a multimillion dollar project and the impact is $1,000, the managers will probably take the risk. If the project is several thousand dollars and the impact is the same, the risk may not be acceptable. These considerations have to be weighed. Another important factor, which I feel affects how much risk to accept, is how long the risk may last. How quickly will the land heal?

The last thing that I think influences operational decisionmaking is how acceptable will the current decision on risk be in the future? I have been told that sometimes litigation with the Forest Service is like shooting at a moving target. The Forest Service plans things and 6 years later, sees the results. Then the lawsuits are filed for our past decisions. The decisions were initially made based on the best information then available, but things change: Research and experience increases knowledge in the intervening time. We need to be aware of this and take it into account in our decisionmaking process. Listen to the experts. Listen to what they know and don't know so you can make decisions on that basis.

Speaker 4: JOSEPH H. HARN--Land managers are continually confronted with the need to address the question of "risk" for all resources, not just for timber. They must also deal with a high degree of ambiguity. This requires a committment of resources and effort to gain certain types of information necessary for risk assessment. For example, if the manager considers water quality, fisheries aspects and the potential for landslides affecting these resources, there are eight or nine laws which must be dealt with. These laws direct the manager to address and attempt to mitigate or protect all of those resources. With all of these requirements and directions to consider, it is important that the land manager, the decisionmaker, receive the best type of information available to make decisions. Unfortunately, all of the necessary answers are not available. Many of the processes or techniques being used or that have been used in the past give an illusion of accuracy that just isn't there. That illusion of accuracy at times

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has and still does give land managers problems.

As one land manager I know stated "We have much data but little information to work with in developing some of our decisions."

Let's take a look at the thought process a land manager might go through, or should go through, when assessing risk. Number one, the manager needs to identify the potential for instability in any land areas considered for harvest operation. The manager then needs to assess the type of injury or losses that could occur and to whom or to what. Finally, it is necessary to determine the consequences or magnitude of these potential impacts or losses. The questions that might be asked are: Will slope failure lower productivity of the lands? Will slope failure have adverse effects on other resources? Will slope failure lower the value of other investments and improvements or destroy them? These are all questions which must be addressed and put into a context that allows the manager to balance immediate concerns with all other resource values and special interests which may be involved in any project.

There are lots of methods for assessing risk that can be considered by the manager. We are not operating in a vacuum with an absolute lack of knowledge. Much can be learned from past successes and failures. For example, in the Coast Range of northern California where much of my experience has been, there is some 50 years of experience to look at. Inventory systems can also be used to gather more and better information. It has been mentioned during this workshop that geological resource inventories in some National Forests have helped to increase the level of resolution of stability hazards. Finally, management procedures can be developed to assure adequate analysis of potentially high risk areas. These procedures can be used to address and mitigate risks. Let me give you an example. The Six Rivers National Forest in northern California went through such a process. It was determined that most of the damage to water quality and fisheries values caused by mass wasting resulted from failures on slopes of 70 percent gradient or higher. It was also found that by looking at data already in hand, supplemented with information from an available geological resources inventory, that 12 percent of the Forest fell into this high-risk category. About 16 percent of the remaining old-growth forest occurred within this 12 percent. Based on this information, management was able to concentrate existing professional resources and determine where time and financial resources were most needed. This allowed forest managers to concentrate their efforts on a restricted area where very difficult decisions had to be made.

Through the use of resources that are available and analysis of information obtained from past experience, I believe we are making workable decisions today. Unfortunately, precision and accuracy are still lacking. In the future we may be able to take the illusion of accuracy we have today and make it truth.

Speaker 5: KENNETH D. WEYERS--There are several points dealing with the concept of risk that I want to put into practical perspective. First, risk is in the eyes of the beholder or manager. The risk could be unplanned expenses; the loss of a facility such as a road, bridge or building; or excessive environmental damage. Risk could also be loss of creditability for you, your organization, your community, or unit. A risk that hasn't yet been mentioned in this workshop, but should be, is personal liability. It has become an issue in a number of recent instances. Finally there is program variability. What is the risk that harvest and road construction plans will change over time, and what will be the cost of these changes? An adequate assessment of risk, whatever the definition, is essential for effective management of forest lands today. As others have said in this workshop, the easy management decisions have all been made. In sensitive areas, and most areas seem to be sensitive today, there are only two choices. One choice is to go elsewhere. The other choice is to enter the area and do the best possible job of minimizing any current risk given existing economic, social, or political constraints. As a manager, I can tell you that the second choice is the one you will probably be considering.

How do managers cope with slope stability when risk is involved? I can speak knowledgeably only about the Payette National Forest on this process.

The Payette is fortunate in having developed a system that deals with both short- and long-term impacts from forest operations at a level felt to be adequate given current limitations in funds and staffing. The system goes something like this:

A land systems inventory was developed for the entire forest that describes and delimits the physical characteristics of the soil and terrain. Superimposed on this inventory were project level guidelines, which identify high and low cost, and high and low sensitivity areas based on identified economic and environmental values. In addition, the constraints that were necessary to hold risks associated with harvesting to a minimum were modeled constraints over both time and space to evaluate short- and long-term impacts.

While I am impressed with the amount of technology that has been developed, especially as it relates to slope stability aspects, as a manager I cannot ask or let specialists do more then what is needed commensurate with the level of decision to be made. Given current staffing and budget limitations, major undertakings to collect more and better data are not affordable. Specialists who work on the ground, who know the ground, are the key to our risk assessment

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program. Their professional judgment is where we start. Research and forest specialists must interact as much as possible so that newly developed techniques and data can be more readily transferred to operational personnel.

My concern lies in the needs for the future. It lies in the urgent need for process understanding and methodologies for assessing and managing cumulative effects.

Question Before Panel 3: Given the social-political constraints imposed on the land manager and levels of risk currently acceptable, what information and levels of application are needed for improved land management decisionmaking?

Speaker 1: **W. W. BOURGEOIS**--The land manager of today must consider a number of technical and political factors when making decisions. The area being discussed in this workshop is terrain stability but this factor cannot be considered in isolation. All other factors that affect and are affected by terrain stability are integral components of any land management decision. It is this integration that must be considered when addressing the need for: (1) required information and levels of application for improved land management decisionmaking, and (2) the direction of future research and management to accomplish these goals.

INFORMATION NEEDS AND LEVELS OF APPLICATION

In answering the question of information needs and levels of application for improved land management decision-making in unstable terrain, I have made two assumptions:

1. The principal activity for the area is forest management in an integrated resource context and

2. Timber development and harvesting are planned for unstable areas.

The information readily available to land managers varies depending on geographic region and organization. Nevertheless, there are basic units of information required for any logical land management decisionmaking process in potentially unstable terrain. These units should include:

1. What resource values exist in the area.

2. Terrain stability maps (1:20,000) that identify potential problem areas.

3. A detailed plan for timber development and harvesting.

4. A site-specific assessment of potential problem areas relative to detailed development plans.

5. A detailed, on-site analysis of soil and rock materials.

6. An assessment of possibility of failure.

Identification of the resource values present is essential for any land management decision. The management practices suitable for unstable terrain in areas that include important fisheries, esthetic or domestic water resources would be considerably different than those necessary when the forest resource is the only high-value resource present. Along coastal British Columbia it is not uncommon to have the same constraints imposed on timber development or harvesting in potentially unstable terrain regardless of the value of other resources present. This, in my view, is inflexible land management and must be challenged if the forest industry is to remain viable and practice good integrated resource management.

In most instances terrain and derived stability maps at a scale of 1:20,000 are a sufficient and cost effective way of identifying potential problem areas that must be incorporated into timber development and harvesting plans. The information supplied by these maps allows the engineer to develop plans that incorporate technical limitations of equipment and other potential problems, (for example, windthrow) with planned activities. The maps also identify the terrain areas where detailed on-site assessments are required to clarify and confirm the potential problems associated with timber development and harvesting.

The site-specific assessments that follow detailed planning allow the engineer and terrain specialist to refine the plans and be more confident in predicting the potential terrain stability problems. Such assessments also allow the assignment of a developed, subjective probability of failure to the area and a decision on whether a detailed engineering soil or material analysis is required. This requirement is expected to be the exception rather than the rule and would usually be associated with very high-value forest or nontimber resources.

It is my opinion that if the land manager is provided with the above resource data and has technical personnel follow the suggested steps the manager will improve the decisions made in unstable terrain. The resources and values have been identified, the potential terrain stability

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problems associated with planned development and harvesting practices have been highlighted, and the probability of landslides associated with these practices assigned. These factors can then be used by the manager in association with economic and political factors to make the final decision regarding land management.

AREAS FOR RESEARCH

The previous discussion regarding the information needs and levels of application includes a number of instances where subjective assessments are made based on experiences or limited quantitative data. It is my opinion that a terrain classification system such as that developed by the British Columbia Ministry of Environment, used in conjunction with existing research data by a pedologist or geologist experienced in terrain analysis is sufficient to accurately identify potentially unstable terrain. The priority areas for research information needed for decisionmaking in unstable terrain can be summarized as follows:

1. Long-term assessments of the effects of present and proposed timber development and harvesting techniques on terrain stability.

2. Long-term implications of landslides on nontimber resources.

3. Techniques for rehabilitation of landslides.

4. Logging and silvicultural techniques to enhance or maintain stability in localized areas.

5. Development of logging practices around gullies to minimize the potential and magnitude of landslides.

6. Evaluation of probability of failure incorporating a statistical and geographical approach to assigning probability of failures within a mapping unit.

7. The application of classical engineering slope-stability models to terrain mapping systems.

The research data and experience presently available provide us with an indication of the effects that our current timber development and harvesting practices have on terrain stability. A degree of subjective assessment is involved, however, and long-term monitoring studies of specific practices would be beneficial to quantify and clarify the expected effects. The practices to be studied should include not only those presently proposed for unstable terrain but also other practices that appear practical and could reduce impacts. I would like to challenge the engineering community to propose new practices for study and to work with the pedologist or geologist in evaluating the impacts of these practices on terrain stability. To date, new or innovative timber development and harvesting practices are rare. Although we do not feel all of the practices proposed by the environmental community are realistic some practices may be applicable and it could be to our benefit to work with such groups to evaluate their ideas.

There are long-term studies being conducted to evaluate the impacts of landslides on nontimber resources in both Canada and the United States. I suggest that more are required and a long-term commitment for support should be obtained from the funding agencies. We are still making decisions on impacts based on inconclusive data. It is my feeling that in many cases the constraints being applied are too restrictive, but this comment is not in all instances based on sound research data.

Where impacts are shown to be significant, alternative methods of rehabilitation either of the landslide or stream need to be evaluated on a cost-benefit basis and within an integrated resource management context. Research into various mitigation and restoration practices, such as the rehabilitation of landslides, needs to be conducted to determine the viability of such practices and the associated costs and benefits.

Frequently managers are in a situation involving terrain where the root deterioration following clearcut logging is expected to decrease the terrain stability to an unacceptable level. Most commonly, in coastal British Columbia such areas are deferred from harvesting. This action can not only involve loss of forest resource but the activities adjacent to the area can induce windthrow in the deferred area. Methods other than or in conjunction with clearcut logging need to be investigated to determine their effectiveness in maintaining or enhancing the terrain stability.

One of our more problematic landforms is gullied terrain, including areas with single or multiple gullies. Inevitably gully sides are unstable or potentially unstable, and when the adjacent areas are clearcut the timber within the gully is often subject to windthrow. To protect gullies, considerable areas of timber would have to be deferred from harvesting. Consequently, these areas are often harvested with precautions taken to minimize the effects of logging. The manner of harvest and postharvest cleanup needs considerable research to determine the most effective methods to decrease terrain instability and to reduce the windthrow potential.

The present methods used to determine the probability of logging practices inducing landslides tend to be subjective in nature. This approach has not created problems to date; however, more quantitative methods are required to substantiate stability assessments. The development and evaluation of statistical and geographical methods for assigning probabilities of failure within mapping units is one suggested method of improving assessments. The potential for adapting classical engineering slope-stability models to terrain mapping systems should also be evaluated to see if the techniques can improve assessment of landslide porbability. All of these methods should be related to terrain mapping because this technique has been shown to be an effective and practical way of identifying problem areas and potentially unstable terrain.

MANAGEMENT IMPROVEMENT

Improvements in decisionmaking regarding unstable terrain are not restricted to better technical data on forest engineering practices or terrain analyses. Land managers need to institute management policies and systems that better utilize existing and developing information. The areas where I believe improvements can be made are:

1. The availability of rapid and effective analytical methods for use in assessing harvest plans; that is, "computerized planning."
2. The active use of existing methods for long-term planning in unstable areas.
3. The clarification of resource management objectives prior to developing an unstable watershed or area.
4. The strict application of known practices in both identified unstable areas and those where poor practices could create unstable conditions.

The earlier discussion on information needs identified the evaluation of timber development plans relative to terrain data. Commonly the plan most desirable to the forest engineer is not acceptable to the terrain specialist if landslides are to be prevented or minimized. This leads to the need for evaluation of both the feasibility and economics of various possible plans. The failure to have a computerized system whereby evaluations can be made rapidly and effectively usually results in inefficiencies and, frequently, questionable land management decisions. Systems are available that can do these assessments and should be actively used by managers.

Long-term planning or liquidation planning is commonly discounted due to future uncertainties and availability of personnel. Failure to do this type of planning in unstable terrain can increase development and harvesting costs through lack of consideration of potential problems in the future. Given the present cost of road construction one error of this type can easily cover the cost of the planning.

Establishing management objectives for all resources in areas or watersheds with unstable terrain is essential. Without a clear definition of these objectives there is a tendency to practice single rather than integrated resource management. Managers are in an era when forest land managers must understand and address the management objectives of all resources in technical, economic, and political contexts.

There are many road construction and harvesting practices known today that, if strictly applied, will minimize acceleration of landslides in unstable and potentially unstable terrain. You are all familiar with instances where proper installation of culverts and ditches would have prevented landslides. It is all too easy for the engineer to allow a practice to be performed that is cost effective during the construction phase with little regard for future costs. The land manager must insist that proper engineering practices be applied in unstable and potentially unstable terrain. If such practices are consistantly applied, I believe a significant number of landslides can be prevented.

SUMMARY

I have presented to you what I believe to be the information needs and levels of application required for improved land management decisionmaking in areas of unstable terrain. Generally, I believe we have methods available that, when applied with terrain and other resource data, can identify potential problem areas. In the past, subjective assessments of terrain stability have been adequate, but I feel pressures will be applied to develop more quantitative methods. Research into these methods and the long-term impacts of current practices on terrain stability and other resources are required. New techniques for rehabilitating landslides and mitigating the impacts of landslides on forest and other resources are also priority research areas. The instituting of management policies and systems that allow for the rapid evaluation of resource management objectives and plans, and the conscientious application of existing data and methods will improve the quality of land management decisions.

Speaker 2: DICK OLSEN--In western Washington, outside of Forest Service lands, most of the harvesting has been completed in most of the drainages. Our opportunity to plan new entry into drainages is already gone. Managers must focus on fixing past errors and making sure they do not make these same errors in the future as second-growth areas are reentered. Also, existing resources must be managed so that impacts on people and other resources are minimized.

To do this, more information and new ideas are needed to help predict and stabilize soil failures related to roads, midslope harvesting, and occurrences in gorges and along stream banks. Of prime importance in my District is how to reduce excessive debris loading in stream channels and destructive downstream scouring effects. I also need answers to help predict the occurrence of landslides and reduce the hazard

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to life and property downslope from harvest areas.

The answers to some specific questions would greatly assist me in more effective harvest planning and hazard reduction. For example: Does the speed of harvesting effect slope stability? Are there species or planting densities that I can use to reduce the risk of landslides on unstable slopes? I could also use more quantitative information on how water retention and movement through the soil affects the stability within a drainage.

Finally, I see an increasing need for techniques to effectively deal with people living next to and below my management areas. In effect, I need the data and techniques necessary to manage my forest lands with a minimum of increased damage to my neighbors.

Speaker 3: DALE J. McGREER—The panel members addressing needs and priorities for effective stability hazard assessment were asked to answer rather complex questions. Those questions carried the presupposition that social and political constraints are imposed that determine "acceptable" levels of risk and that these are "given." I preface my response to the panel's questions by noting that acceptable levels of risk are not "given." They are not because they can seldom be defined quantitatively. If acceptable levels of risk could be adequately quantified, it would follow that probabilities of mass failure could also be adequately quantified. In reality they seldom are.

Social and political constraints certainly influence a land manager's decisionmaking processes. Such constraints influence attitudes towards acceptable levels of risk but fall short of defining them. Acceptable levels of risk vary with circumstances, physical as well as social, and social attitudes change with time. Ultimately, it is the responsibility of the professional land manager to accept some level of risk, whether the level can be defined or not. The more accurately he can access risk, the more rationally he can make land management decisions. And the manager faced with certain knowledge of risk, but without the means to assess its severity will all too often choose to avoid the risk entirely.

The problem of defining and controlling levels of risk associated with land management actions is at the heart of the questions posed to the panel. The first of the two questions is What information and levels of application are needed for improved land management decisionmaking in areas of unstable terrain?

To make rational decisions in the face of known unstable terrain, a manager needs to know the probabilities of failure associated with specific management actions. Two types of knowledge may be necessary: (1) rates and types of natural mass failures through time, and (2) probabilities of failures caused by human activities. Such probabilities are most meaningful in the context of probabilities per unit activity and per unit time. A simplified example might be to assess the probability of a debris torrent per mile of road system per year given sidecast tractor construction on 60 to 70 percent slopes. If enough information on probability of failure for this base case can be provided, the next step would be to assess incremental levels of hazard reduction associated with alternative practices.

Another approach to hazard assessment, and one that can be incorporated into the first, is to assess probabilities of failure on a specific site or problem basis; for example, construction across a rocky, steep, spur ridge or through a deeply encised first-order stream.

Assessing probability of failure, given construction without special design features, is the fundamental first step. If the probability of failure with standard practices is judged too high, then the manager needs to evaluate application of specific engineering solutions. Many situations are encountered where proven solutions exist but they are not known to the technical and administrative personnel that make the decisions on whether or not to proceed. Again, faced with a risk of unknown magnitude, the manager will all too often choose the option carrying no risk. If knowledge of the effectiveness and cost of solutions to specific problems can be provided, the choices broaden considerably.

In answering the second question, "where should research and management be headed to accomplish these goals?" I take the stand that a great deal of information and experience now exists. Needed are concentrated efforts to collect, analyze, and synthesize existing information and make it available in a straightforward manner that encourages its use by engineers. A great number of surveys have been done on specific forests, ownerships, and geographic areas to define the probabilities of mass failure associated with specific geomorphic characteristics. Some of these surveys provide detailed information on the geomorphic character of the mass failures; the type of landforms, soils, and geologic materials upon which they occurred; and detailed information on associated management practices.

More surveys are needed. But even now it may be possible to calculate probabilities of failure given certain geomorphic characteristics and practices. These calculations would likely take the form of a model. It is doubtful that the model would be highly accurate—which is the common situation for most models now in use in many earth sciences disciplines. Models might well be reliable enough, however, to allow more rational decisionmaking than if they did not

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exist. A characteristic of many of the recent land management models is that they often make specific areas of knowledge that are currently insufficient painfully evident. They provide information on what types of data are necessary to allow more rational decisionmaking processes. Research can then play a direct, useful role.

Speaker 4: MICHAEL J. COOK--As described during the last 1 1/2 days, there exists a wealth of information and a number of techniques for stability hazard assessment ranging from factors of safety to computer programs capable of producing answers to six decimal points. These techniques, of course, come with the caution, do not use because of limited accuracy. Participants have also been told that over 2,500 years of experience are represented at the workshop. A problem that I see is that we have all that information, all that experience, and all these techniques contained in or being developed at widely scattered places and being dispersed in many unregulated directions.

I get the impression that as managers, using the techniques described in this workshop, we would have about a 1:100 chance of providing the right solution to the right problem: This is not good enough. Engineers, soil scientists, geotechnical specialists and university professors working on this problem, must not lose sight of the fact that they are providing a service to the decisionmaker. Given the existing social and political constraints, the decisionmaker needs to be provided with the most cost-effective and accurate methods of estimating the probability of failure and the extent of damage if the proposed activity is conducted.

The question of where research and management need to be headed is very appropriate at this time. Sharing viewpoints on this question is probably one of the principal values of a workshop like this. I see a real opportunity and an absolute necessity for National Forest administration, research, universities and industry to work together as a cost-effective team that can be utilized to improve techniques for assessing failure potential or damage on lands which are scheduled for entry. A major way that research and operating organizations can assist, is to pull together much of the available information that has been put forth here in the last few days and provide those specialists assisting the land managers with the most up-to-date tools that are available. In other words, I think we need to provide an effective means of transferring this knowledge among the different individuals and organizations representing forestry concerns. And we need to listen to the group represented here today, especially the managers, as far as to what they need, where they are headed, and what research can do to provide the assistance they need.

Speaker 5: TED STUBBLEFIELD--When National Forest management activities are proposed for unstable terrain, the decisionmaker needs to include the following three primary pieces of information in the decision process:

1. The risk of hillslope failure, as a result of the proposed activity. The risk should be expressed in terms of a probability of occurrence or chance of failure during a specified period of time. For example, the chances of hillslope failure as a result of clearcut "X" or "Y" (or Road "A" or "B") are 10 percent per year for the next 10 years. The degree of accuracy of the estimate also needs to be stated.

2. The consequences of hillslope failure. Hillslope movement may have minor or major consequences depending on numerous factors. The primary consequences that must be considered are:

A. Capital investment damage (roads, bridges, buildings).

B. Site productivity loss (on-site and off-site).

C. Impact on the riparian and aquatic systems.

D. Visual impact.

E. Cummulative effects, including long-term management and public concerns.

3. Management options. Spatial positioning of units, harvest methods, silvicultural systems, road location and design, and fuel treatment alternatives must be examined relative to the risks and consequences of hillslope failure. The option of "no treatment or entry" must also be analyzed. Reformulation of the proposed alternative and a new risk assessment may be required.

With the knowledge of the potential risks, consequences and options supplied by staff (specialists), the decisionmaker can then determine whether the risk is acceptable compared to the benefits of the proposed action.

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DIRECTION FOR RESEARCH AND MANAGEMENT

Information available to the decisionmaker can be improved in three significant areas.

1. Analysis of alternative land management prescriptions (research). Much research has focused on the land stability effects of clearcutting as a treatment. More information is needed about other variable harvest intensity prescriptions. For example, how would partial cutting reduce risk of failure (if any)? Similarly, research has pointed to roads as a management activity responsible for most landslides. But what are the specific design factors of National Forest roads that contribute most to road-caused landslides?

2. Determine acceptable thresholds of risk (management). National Forest managers and decisionmakers must improve their ability to state clearly what level of risk they are willing to accept. Management decisions about unstable terrain will continue to be of a subjective nature. But, managers must strive toward a quantitative and factual approach in decisionmaking.

3. Technology transfer. The transfer of knowledge between research and management is of vital importance. For example, research has developed the techniques to determine the risk of failure, but the techniques are not in common practice in the National Forest System. Technology transfer is not a one-way street from research to management, but rather, a three-way sharing of responsibility where the decisionmaker asks the right questions; the scientist develops techniques and makes them available; and the staff (soil scientist, geologist, engineer, hydrologist, etc.) seek the new information and bring it into practice. The process is best served by a continuum of information exchanges, often via workshops.

STATUS OF KNOWLEDGE--
RELIABILITY OF TECHNIQUES--
DIRECTION FOR IMPROVED DECISION MAKING

Jeff Sirmon

STATUS OF KNOWLEDGE

It is clear to me after listening to the presentations and discussions generated by this workshop, that knowledge of the nature, location, and extent of unstable soils is variable in the western U.S. and Canada. Knowledge of specific failure mechanisms and potential impacts on forest resource mangement is even more variable. In the Pacific Northwest Region of the USDA Forest Service, relatively good knowledge of the extent of unstable soils exists on a forest by forest basis. This knowledge has come through a sequence of inventories and special investigations beginning with a mantle stability survey in the early 1960's. This was followed by our soil resource inventories at 1 inch per mile. We have also conducted a number of special soil, geologic, and hydrologic investigations and inventories in some of the critical watersheds in the Region. For example, staff specialists on the Siuslaw, Siskiyou, and Rogue River National Forests in Oregon have developed some fairly sophisticated assessments of landslide risk so that managers can predict with reasonably high accuracy where events might occur and the expected volume of material that would be generated from such failures.

I believe that our biggest knowledge gap is one of determining what the environmental impacts of land failures are on our resources. For example, one of the areas of greatest concern in the Pacific Northwest is the potential effect of landslides on anadromous fisheries. Yet, even our specialists don't have a clear understanding of what the effects of landslides are. Certainly it is generally accepted that when channel scouring occurs there will be at least a temporary loss of spawning and rearing habitat. It is also generally known that debris jams can block fish from passing to large areas of otherwise suitable fish habitat. Recent studies by biologists at the Pacific Northwest Forest and Range Experiment Station suggest that, except for stream blockage, some streams are deficient in large woody debris. Studies addressing this subject, being done by Fred Everest in the Siuslaw National Forest, will be valuable to managers in the future.

Another deficiency is a lack of understanding of the effect of landslides on site productivity of commercial tree species. In many cases, the actual failure area is extremely small and has little direct effect on forest productivity. I don't think we fully understand, however, the soil replacement process. That is, when failures do occur, where does the soil come from and to what extent does this affect overall site potential.

I believe there is also a need to better differentiate between long-term natural erosion rates and those rates affected by management activities in a basin. This would permit managers to do a better job of monitoring to see how well they are doing.

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Along much of the Pacific coast of the United States, the major road network is in place. For those areas that are as yet unroaded, we have sufficient information to establish potential risk of failure on most of the public lands. On many private lands, this may not be the case. From this general information on relative risk, managers know where to focus most of their attention for site investigations for actual road design. Thus, it seems that managers need to apply the information and techniques that are already available. They also need to do a better job of analyzing the tradeoffs from planned activities. Where managers have major resource conflicts, with high values, there needs to be a better assessment of the tradeoffs.

Finally, managers also know that it is extremely costly to rehabilitate areas where slides occur and that it is cheaper to prevent failures than to try to rehabilitate.

RELIABILITY OF EXISTING TECHNIQUES

Several speakers have addressed the question of reliability of predicting landslides. It is clear that there are different degrees of reliability depending upon failure mechanisms, level of inventory, types of environment (rock type, soils, climate), and past experience.

For example, there are some geotechnical procedures that are quite accurate for very specific sites. On the other hand, application of such techniques can be unreliable with respect to an entire drainage system if there isn't a commensurate inventory of the relative hazards and risks of failure. Reliability, therefore, is really a function of the degree of an integrated assessment of a particular basin, and it is critical that a systematic inventory, analysis and monitoring process be in place. Techniques for predicting and preventing major land failures need to be systematized from a broad assessment to site specific locations. For this reason, a truly interdisciplinary approach is needed and should include geologists, soil scientists, hydrologists, fish biologists, and engineers, together with silviculturists, logging specialists, and others as appropriate.

It may not be necessary to predict every landslide that potentially can occur, but managers, aided by their specialists should be able to predict the major events so that activities in those areas can be avoided or structures designed to mitigate or prevent landslides from unnecessary occurrence.

IMPROVED DECISIONMAKING

Decisionmaking can be improved by a variety of techniques and methods. Each organization and the levels within an organization make decisions differently.

Decisions related to slope stability require comprehensive assessments and analysis because the greatest impacts may occur downstream from the intended activity. Activities planned on lower slopes need to be assessed in terms of how such activities might be affected by unstable lands upslope.

Analysis must be truly interdisciplinary, beginning by looking at the nature of the landscape and processes operating on the landscape from a broad view using small-scale photos (1 to 70,000 or smaller depending on the intended activity) and then focusing on site specific investigations. One example of how this is being done in the Pacific Northwest Region of the Forest Service is that the most severly unstable lands are being identified as unsuited for timber management because of expected irreversible damage to soil productivity or watershed condition in accord with the National Forest Management Act. Then, on those lands that remain in the productive base, a rational decisionmaking process is developed that allows for prediction with an acceptable confidence, or risk, of what the potential impacts will be and what the tradeoffs are, including costs. The decisionmaking process can be improved by applying sound analytical techniques from interdisciplinary functions and by having available the appropriate level of inventory and design specifications for the magnitude of the potential problems and the values at stake.

METRIC EQUIVALENTS

LENGTH

1 inch (in.) = 25.40 millimeters (mm.)
1 inch (in.) = 2.54 centimeters (cm.)
1 foot (ft.) = 30.50 centimeters (cm.)
1 foot (ft.) = 0.31 meters (m.)
1 yard (yd.) = 91.40 centimeters (cm.)
1 yard (yd.) = 0.91 meters (m.)
1 mile (mi.) = 1609.00 meters (m.)
1 mile (mi.) = 1.61 kilometers (km.)

MASS

1 pound-mass (lb.) = 453.60 grams-mass (g.)
1 pound-mass (lb.) = 0.45 kilograms-mass (kg.)
1 ton-mass (tn.) = 907.20 kilograms-mass (kg.)
1 ton-mass (tn.) = 0.91 megagrams-mass (Mg.)

AREA

1 acre (ac.) = 2.47 hectares (ha.)
1 square inch (in.^{2}) = 6.47 square centimeters (cm.^{2})
1 square foot (ft.^{2}) = 929.00 square centimeters (cm.^{2})
1 square foot (ft.^{2}) = 0.09 square centimeters (cm.^{2})
1 square yard (yd.^{2}) = 8361.00 square centimeters (cm.^{2})
1 square yard (yd.^{2}) = 0.84 square meters (m.^{2})
1 square mile (mi.^{2}) = 2.54 square kilometers (km.^{2})
1 square mile (mi.^{2}) = 254.00 hectares (ha.)

VOLUME

1 cubic inch (in.^{3}) = 16.39 cubic centimeters (m^3)
1 cubic foot (ft.^{3}) = 0.03 cubic meters (m^3)
1 cubic yard (yd.^{3}) = 0.76 cubic meters (m^3)
1000 board feet (BF) = 5.60 cubic meters (m^3) (Schribner scale)

FORCE

1 pound-force (lb) = 0.45 kilograms-force (kg.)
1 pound-force (lb) = 4.45 newtons (N)
1 pound-force (lb) = 0.0005 megagrams-force (Mg.)
1 ton-force (tn.) = 0.91 megagrams-force (Mg.)
1 ton-force (tn.) = 8.89 kilonewtons (kN)

STRESS AND PRESSURE

1 pound-force per square inch (psi) = 0.07 kilograms per square centimeter (kg/cm^2)
1 pound-force per square inch (psi) = 6.89 kilopascals (kPa)
1 pound-force per square foot (psf) = 4.88 kilolgrams-force per square meter (kg/m^2)
1 pound-force per square foot (psf) = 47.88 pascals (Pa)

DENSITY AND UNIT WEIGHT

1 pound-mass per cubic foot (pcf) = 0.02 grams-mass per cubic centimeter (g/cm^3)
1 pound-mass per cubic foot (pcf) = 16.02 kilograms-mass per cubic meter (Kg/m^3)
1 pound-mas per cubic foot (pcf) = 0.02 megagrams-mass per cubic meter (Mg/m^3)

Swanston, Douglas N., tech. ed. Proceedings of a workshop on slope stability: problems and solutions in forest management. Gen. Tech. Rep. PNW-180. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1985. 122 p.

The workshop provided mid and upper level forest managers and technical specialists with an overview of slop stability problems on forest lands, current state of knowledge, and practical techniques available for problem solving.

Keywords: Slope stability, landslide.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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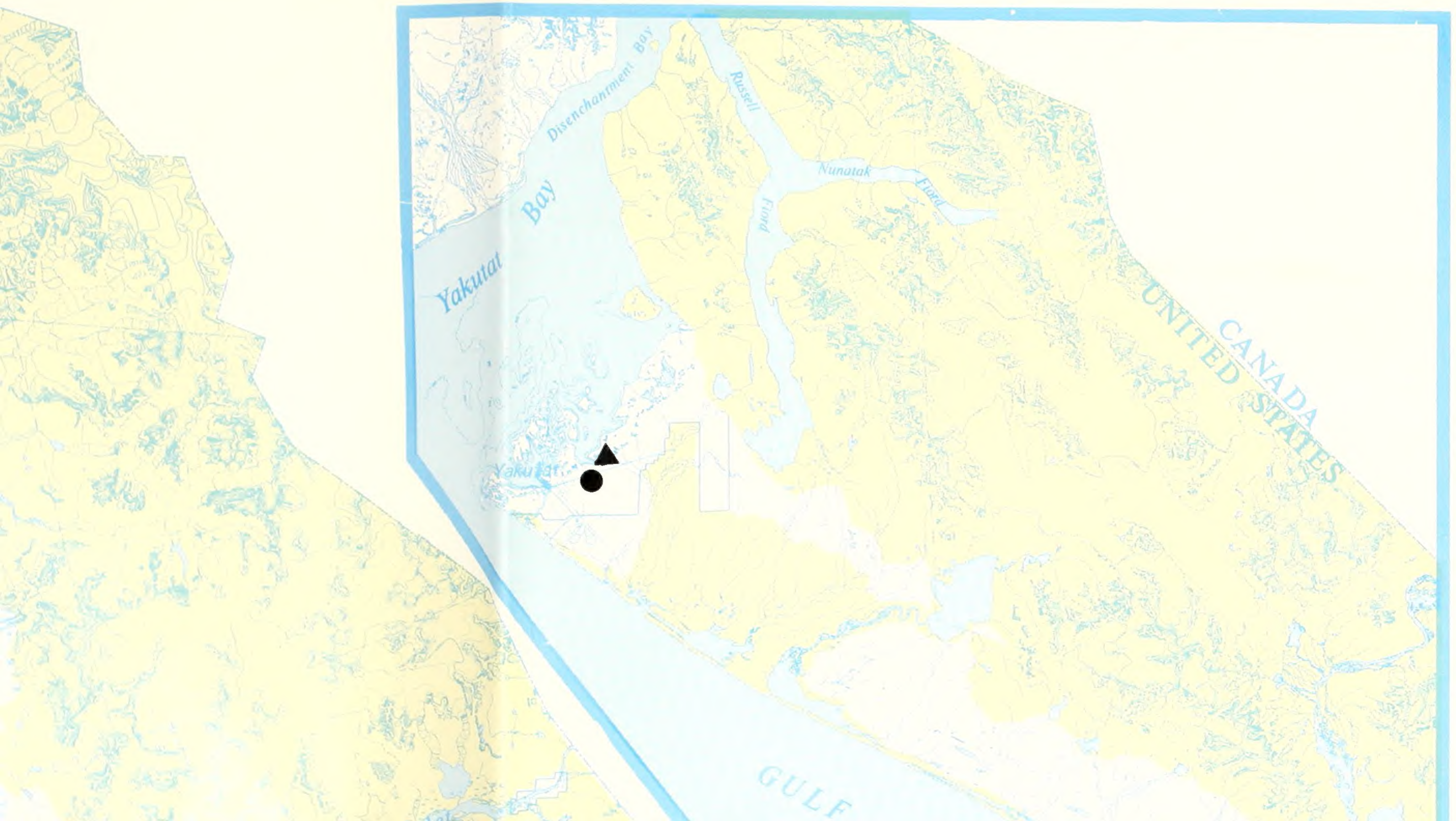
SOUTHEAST ALASKA TIDELAND LOCATIONS FOR LOG TRANSFER AND STORAGE



Pocket Supplement

Pacific Northwest Forest & Range Experiment Station
General Technical Report PNW-174

"Log Transfer And Storage Facilities
In Southeast Alaska: A Review"

1984

By

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